European Commission

Study on the designation of Renewables Acceleration Areas (RAAs) for onshore and offshore wind and solar photovoltaic energy

Final Report

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Study on the designation of Renewables Acceleration Areas (RAAs) for onshore and offshore wind and solar photovoltaic energy

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Acronyms

AA	Appropriate Assessment under Article 6(3) of the Habitats Directive
AC cable	Armour-clad cable
ApER	Renewable Energy Acceleration bill (l'Accélération de la Production d'Energies Renouvelables) (France)
CAN Europe	Climate Action Network (CAN) Europe
CBD	Convention on Biological Diversity
CHP	Combined heat and power
CSP	Concentrated solar power
EEA	European Environment Agency
EIA	Environmental Impact Assessment
EIHP	Energy Institute Hrvoje Požar (Croatia)
EMF	Electromagnetic field
EMODnet	European Marine Observation and Data Network
EU	European Union
EURING	European Union for Bird Ringing
EUROBATS	Agreement on the Conservation of Populations of European Bats
GEC	Good Environmental Conditions
GHG	Greenhouse Gas
GES	Good Environmental Status
GIS	Geographic information systems
HVDC cable	High voltage direct current cable
IAS	Invasive alien species
IMMAs	Important Marine Mammal Areas
IUCN	International Union for Conservation of Nature
MSFD	Marine Strategy Framework Directive
MSPD	Maritime Spatial Planning Directive
MS	Member State
NGO	Non-Governmental Organisation
NSEC	North Seas Energy Cooperation
ODIM	OSPAR Commission Data and Information Management System
PV	Photo-Voltaic
RAA	Renewables Acceleration Areas
RE	Renewable energy
RED	Renewable Energy Directive
RES	Renewable Energy Sources
SEA	Strategic Environmental Assessment

1. Introduction

Article 15c of the revised RED[1], obliges EU Member States to "*adopt one or more plans designating […] renewables acceleration areas for one or more types of renewable energy sources*". The identification of areas suitable to be designated as renewables acceleration areas has to follow the requirements laid down in Article 15c(1)(a).

Article 15c(1)(a) indicates that Member States should give priority to certain types of areas with lower environmental sensitivity, such as artificial or already built areas, which reduces the likelihood of potential impacts. It also excludes certain locations as potential RAAs given the higher likelihood of significant environmental impacts in those areas (e.g., Natura 2000 sites, protected areas, other sensitive biodiversity areas).

This report aims to complement the practical guidance published by the European Commission on 13/5/2024[2], by providing further details and considerations relevant for the RAA designation. The findings of this report are based on best practices identified in Member States, on a wide array of scientific literature sources, and on direct inputs provided by officials and stakeholders involved in the renewables planning process in several Member States. This report also analyses impacts and mitigation measures, focussing on areas that would be suitable for RAA designation, based on the criteria laid out in Article 15c.

1.1. Technologies covered in this analysis

This guidance primarily addresses three main types of renewable energy sources: offshore wind, onshore wind, and solar photovoltaic. These technologies have seen significant advancements in recent years, leading to extensive deployment and diverse options for their design and placement. However, certain designs remain preferred for large-scale development, such as ground-mounted PVs, and horizontal axis wind turbines. These are the focus of the analysis which identifies and describes their key environmental impacts. However, when relevant, specific considerations for different designs of a certain technology (e.g., bottom-fixed offshore wind and floating offshore wind) are discussed in the text.

Solar energy encompasses various designs and types of installations, including roof-mounted and ground-mounted photovoltaic (PV) systems, Concentrated Solar Power (CSP), or floating solar arrays, among others. However, CSP and floating solar arrays have limited applicability, while roof-mounted PVs fall under the shorter permitting requirements set by Article 16d. Therefore, this document focusses on ground-mounted PV systems, which consist of PV arrays installed on the ground, which can vary in size from small-scale installations to utility-scale solar farms, covering hectares of land. Ground-mounted PV systems are well-developed and cost-effective, contributing significantly to the expansion of renewable energy capacity worldwide. Potential environmental impacts to be considered include land use change, habitat disruption, and soil erosion, although proper siting and land management practices can mitigate these impacts.

Wind energy encompasses various types of installations[3], including onshore and offshore wind farms, both bottom-fixed and floating.

[1] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (OJ L 328 21.12.2018, p. 82), as amended by Directive (EU) 2023/2413 (OJ L, 2023/2413, 31.10.2023).

[2] Directorate-General for Energy (2024): Guidance on designating renewables acceleration areas (SWD) [Guidance on designating renewables acceleration areas - European Commission (europa.eu)]

[3] Only horizontal-axis turbines are included in the assessment of environmental impacts, due to the limited deployment of vertical-axis turbines in wind energy projects.

- Onshore Wind: onshore wind projects typically consist of one or multiple turbines (wind farms) mounted on towers erected on land. These turbines harness the kinetic energy of the wind to generate electricity. Onshore wind energy is a well-established and widely deployed renewable energy technology, offering advantages such as relatively low installation costs and ease of access for maintenance. However, onshore wind projects can face challenges related to land use conflicts, visual and noise impacts, and potential effects on local wildlife and habitats.
- Offshore Wind: offshore wind projects are situated in open waters, often located several kilometres offshore. These farms utilise wind turbines anchored to the seabed using various foundation types, including monopiles and jackets (bottom-fixed offshore wind). Offshore wind energy has significant potential to supply an important share of the EU's electricity demand, as offshore wind turbines have a higher load factor than onshore wind energy installations. While locating wind farms offshore can help avoid or minimise some of the challenges associated with onshore installations, they also present specific challenges related to construction, maintenance, and environmental impacts on marine ecosystems. An alternative design option is floating Offshore Wind, which involves deploying wind turbines on floating platforms tethered to the seabed using mooring systems. This technology allows for the installation of wind turbines in deeper waters, where fixed-bottom foundations are not technically or economically feasible, but challenges such as cost, floating platform stability and mooring system design are delaying their uptake. Floating offshore wind projects are not considered in this report.

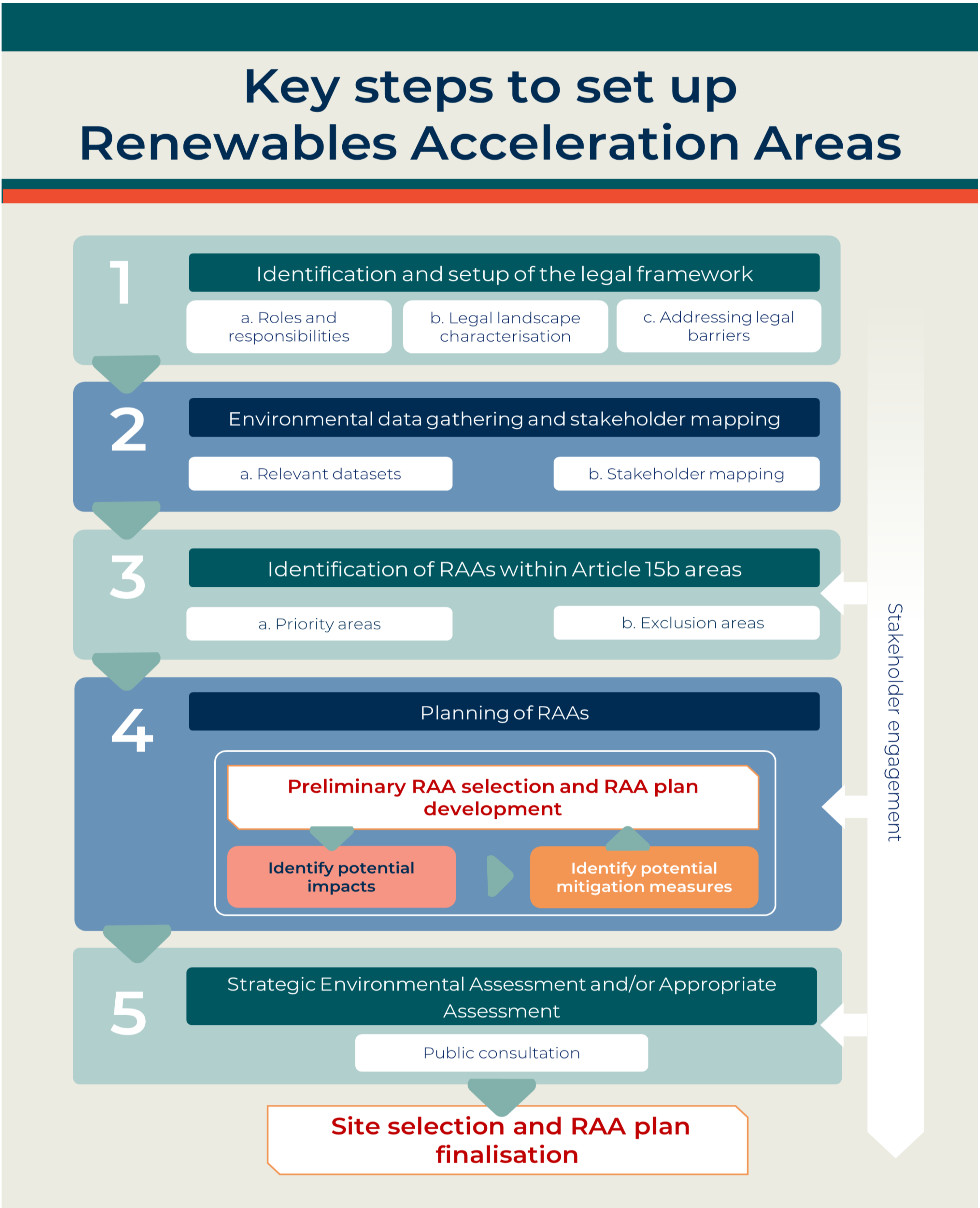
1.2. How to read this report

This report aims to act as a practical reference guide for national authorities undertaking the RAAs identification and designation process. To do so, it first provides a broad overview of the key steps of the process. The report then delves deeper into three key aspects: the process to identify suitable RAAs; the more common impacts that can be expected in these areas from the deployment of onshore wind, offshore wind and solar PV; and the more common mitigation measures that can be implemented to avoid and minimise these impacts. More specifically:

- **Chapter 2** provides an overview of the main steps to identify a renewables acceleration area, as well as summarising impacts and mitigation measures. It also helps to identify where in this report readers can find more details on the specific step.
- **Chapter 3** elaborates possible approaches and key spatial considerations for the process of identifying suitable areas to be designated as RAAs. The chapter then provides information on a variety of tools that can be used to aid the planning process with a view to minimising impacts on nature. Building on the practical examples and case studies, this chapter finally emphasises the importance of stakeholder engagement and highlights various approaches that can increase participation and enhance support for renewable energy projects.
- **Chapter 4** presents the key environmental impacts of onshore wind, offshore wind and solar energy technologies based on a systematic examination of literature. A total of 90 sources were analysed, with almost half of them being peer-reviewed scientific studies. Other sources include technical reports by the European Commission and RE developers, studies published by research institutions investigating environmental impacts of wind and solar technologies, and studies developed by environmental NGOs. Impacts are described through their effects on specific elements of the ecosystem (species, habitats), by providing an estimate of the magnitude and extent of their potential effects on wildlife and considering the specific stage of project development where impacts are likely to occur.

- **Chapter 5** focuses on measures that can be implemented to mitigate the impacts associated with onshore wind, offshore wind and solar energy. Mitigation measures are grouped according to the specific stage of project development where impacts are likely to occur, with a recognition of technology specific causes of the impact.

2. Steps to designate RAAs



1. Identification and setup of the legal framework

Identifying the authorities to be involved and the relevant legal landscape, addressing any legal barrier that might influence the designation of RAAs

a. Roles and responsibilities

Identifying authorities that should be involved in the designation process, their role, and the stage of the process where their input is needed.

SECTION 3.2.1

SECTION 3.2.2

b. Characterisation of the legal landscape

Identifying the relevant pieces of legislation that may influence RAAs designation with a focus on:

- **legal barriers**, such as prohibition of RE plants location in buffer areas adjacent to transport infrastructure and specified minimum distances from residential areas
- **synergies and opportunities**, e.g., legislation under development on related matters, opportunities for multiple space uses.

SECTION 3.2.2

c. Addressing legal barriers

The legal barriers might be:

- **obsolete and/or not aligned with the objective of RE acceleration →** the competent authority should consider amendment of existing legislation and activate the relevant process.
- **still valid in the current framework of RE acceleration →** it should be considered as a constraint in the subsequent mapping exercise outlined below.

SECTION 3.2.2

France – removing limitations on renewable energy development along motorways

In France, land close to motorways and major roads was estimated to have an overall PV potential of 1800 to 2400 MW for the 12000 km of motorways in the country. Article L. 111-6 of the French urban planning code, however, prohibited the construction and installation of PV plants outside urban areas within a 100 m buffer on either side of motorways and intersections, and within a 75 m buffer other roads classified as major traffic arteries. To overcome this barrier, Law n. 2023-175 of 10 March 2023 for RE acceleration (ApER), amended the urban planning code to introduce an explicit derogation from the ban on construction on buffer areas for solar energy infrastructures, PV plants or solar thermal plants.

1. LEGAL FRAMEWORK

2. Data gathering and stakeholder mapping

Gather the necessary data to identify exclusion areas and define the stakeholder consultation strategy.

a. Relevant datasets

Gathering datasets – including GIS - to identify **environmentally sensitive areas to be excluded or considered for exclusion from RAAs plans** pursuant to Article 15c, par. 1(a)(ii) of the RED. These are:

- Natura 2000 sites and areas designated under national protection schemes for nature and biodiversity conservation
- major bird and marine mammal migratory routes
- other areas identified by sensitivity mapping and other tools.

SECTION 3.1

b. Stakeholder mapping

The mapping exercise involves identifying in advance and, if needed, reaching out to, all **actors that might own relevant data**, such as those needed to develop sensitivity maps (e.g. environmental NGOs, academic experts, other public authorities), as well as the **stakeholders that might be affected by the RAAs designation** – such as local communities, electricity grid operators, RE project developers, investors' associations and representatives, NGOs, etc.

SECTION 3.3

Resources

- EURING - Migration Mapping Tool
- BirdLife - Important Bird and Biodiversity Areas
- BirdLife - Seabird Tracking Database
- Kotkakludi - Bird Migration Map
- WWF - Protecting Blue Corridors project
- IUCN - Important Marine Mammal Areas
- ACCOBAMS - Surveys

Croatia - Zadar County pilot project

Zadar County in Croatia served as a pilot project for an integrated RES planning approach – focusing on wind and solar – developed by the Hrvoje Požar Energy Institute (EIHP) in collaboration with The Nature Conservancy (TNC). The planning process included reaching out to several stakeholders during the methodology development, to obtain feedback as well as additional data that were not publicly available. Based on a stakeholder mapping exercise, EIHP identified a set of stakeholders to be invited for further collaboration, including:

- Officials from the relevant Ministries, such as the Ministry of Environment and Energy, the Ministry of Economy and Sustainable Development, the Ministry of Physical Planning, Construction and State Assets,
- Officials from the Zadar County relevant authorities - the Institute of Spatial Planning and the Department for Physical Planning, Environmental Protection and Public Utilities
- Experts from academic institutions, e.g. experts on vulnerable habitats and species
- Environmental NGOs

EIHP consultation strategy encompassed (i) an introductory workshop to set up the collaboration, (ii) several bilateral interviews with specific focus on the methodology for the sensitivity assessment, followed by written feedback, (iii) a peer review workshop and (iv) an online survey, to validate the findings.

2. DATA & STAKEHOLDERS

3. Identification of RAAs within Art. 15b areas

Identifying priority areas and mapping protected, sensitive and constrained areas for exclusion, based on the data gathered in step 2.

a. Mapping of areas necessary for national contributions towards the 2030 renewable energy targets (Article 15b, par. 1 of the RED) – high RE potential

b. Priority areas

Mapping areas that should be prioritised due to their status: they are already developed or have a lower environmental value.

For example, industrial sites, parking areas, degraded agricultural land, etc.

SECTION 3.1.2

c. Exclusion areas

Natura 2000 and other protected areas for nature conservation
These sites must not be included in RAAs planning, except for artificial and built surfaces, e.g. rooftops of existing buildings and parking areas.

SECTION 3.1.1

Other environmentally sensitive areas
Developing a methodology to map environmentally sensitive areas beyond protected areas, to be excluded from RAAs planning, i.e.:

- major marine mammal and bird migratory routes
- other areas identified by sensitivity mapping and other tools

SECTION 3.1.1

Considering constrained and high trade-off zones
Mapping areas subject to legal constraints that are deemed still valid after the assessment of step 1 above, as well as areas with high trade-off potential which would result in sub-optimal siting of RAAs. e.g. buffers around Natura 2000 sites, valuable agricultural land, historical and cultural heritage sites.

SECTION 3.1.3

Sensitivity mapping examples from Belgium and the Netherlands

Innovative comprehensive tools are being developed to integrate ecological modelling into the spatial planning processes. For example:

- In the Flanders region of Belgium, the Biological Valuation Map (BVM) is a uniform field-driven survey of the land cover and vegetation with indication of the related biological valuation. The Flanders authorities also developed wind farms sensitivity maps for birds and bats for assessing areas where siting wind turbines may pose a risk to species. This tool classifies the region into four risk categories.
- In Belgium, the BWZee atlas provides a biological valuation map for the Belgian continental shelf, covering seabirds, macrobenthos, epibenthos and demersal fish. Also in Belgium, the Belgian Marine Data Center collects relevant data for spatial planning, including observations of marine mammals, and stores data from the monitoring programme that spans the Belgian part of the North Sea as part of the MSFD and Natura 2000 monitoring requirements.
- In the Netherlands, the Digitwin North Sea project provides open access to several datasets which are relevant for spatial planning in the North Sea, such as on bird sensitivity.

3. MAPPING

4. Planning of RAAs

Developing the plan of suitable land and sea surfaces for RAAs designation

Areas identified under Article 15b

Areas after exclusions under the RED (protected sites and other sensitive areas)

Areas after additional exclusions – e.g., areas with legal constraints and high trade-off risk. A scenario approach can be used to test different levels of additional exclusion (e.g. different width of buffer areas around protected sites, high-value agricultural land).

SECTION 3.1

Match with priority areas

RAA selection

Identify potential impacts

Identify potential mitigation measures

RAA PLAN

Stakeholder engagement

Several tools are available to reach stakeholders (e.g. task forces and expert consultations). Interinstitutional cooperation, including with the authorities of other Member States should also be planned when relevant.

SECTION 3.3

Portugal – Scenario approach

The Working Group for the Definition of Renewable Energy Acceleration Areas (GTAER) has been tasked by the Ministry of Environment and Climate Action to identify areas with lower environmental and heritage sensitivity for the location of RAAs

The GTAER developed a methodology based on the main following steps:

(i) Data gathering to identify exclusion areas

(ii) Development of GIS datasets and algorithm to subtract from the map of continental Portugal the polygons to be excluded

(iii) Development of draft maps of potential candidate RAAs and scenarios

Five different scenarios were developed. These scenarios represent different policy options which differ in terms of whether or not a few areas subject to controversial constraints or trade-offs were excluded from the potentially suitable sites for RAAs. These included buffers of 100m width from residential and mixed-use buildings, porous aquifers, as well as agricultural and ecological reserves.

This approach was used to test the respective "weight" of the most controversial exclusions under the different scenarios. In addition, it provided options to be compared with the land area needed to meet the renewable energy targets of the country.

5. Strategic Environmental Assessment and Appropriate Assessment

Once the potential siting is identified, the draft RAA plans must undergo the relevant environmental assessments under Directive 2001/42/EC and Directive 92/43/EEC

Strategic Environmental Assessment (SEA)

An environmental report must be prepared where the likely significant effects on the environment of implementing the RAA plan – with the relevant mitigation rulebook - are identified, described and evaluated. The environmental report should also provide for "reasonable alternatives", which might be grounded in the different scenarios developed under Step 4.

Section 5

Appropriate Assessment (AA)

If the RAA plan will likely have a significant negative effects on protected habitats and species, it must also undergo an Appropriate Assessment under Directive 92/43/EEC (Habitats Directive).

Section 5.1

Public consultation

Integration of public participation into environmental assessment procedures is mandated by both Directive 2001/42/EC and Directive 92/43/EEC.

The public and affected authorities must be given an early and effective opportunity within appropriate time frames to express their opinion on the draft plan and the environmental report before its adoption or submission to the legislative procedure.

RAA sites selection FINALISED

5. SEA and AA

KEY ENVIRONMENTAL IMPACTS

ONSHORE WIND

SECTION 4.1

Wildlife mortality and injury	Collision	Birds and bats flying within the rotor swept area are at risk of collisions that may result in injuries and / or deaths.
	Electrocution	Medium voltage power lines are sometimes used by birds, specifically eagles, hawks, vultures, kites, falcons, storks and corvids for perching, roosting and even nesting.
Habitat loss	Habitat loss	Habitat loss occurs when the area surrounding the wind farm has been modified to an extent that it can no longer support its native species.
	Barrier effect	Physical and/or psychological hindrance to movement for birds, bats and terrestrial species due to closely-spaced wind turbines, and development of access roads and transmission lines.
	Displacement of species	Reduced animal presence (birds, bats, and terrestrial mammals) in and around wind farms due to habitat loss or disturbance.
Ecosystem degradation	Habitat degradation	Change in the characteristics of a habitat that affects one of more of the species it support and ecosystem services it can provide.
	Noise pollution	Mechanical noise that comes from the gearboxes and generators, and aerodynamic noise from the turbine blades.

OFFSHORE WIND

SECTION 4.2

Wildlife mortality and injury	Collision	Marine and migratory birds flying within the rotor swept area are at risk of collisions that may result in injuries and / or deaths.
Habitat loss	Habitat loss	Habitat loss occurs when the area surrounding the wind farm has been modified to an extent that can no longer support its native species.
	Barrier effect	Physical and/or psychological hindrance to movement of birds and marine species because of closely-spaced wind turbines.
	Displacement of species	Reduced animal presence (birds, bats) in and around wind farms due to habitat loss or disturbance.
Ecosystem degradation	Habitat degradation	Change in the characteristics of a habitat due to the installation and operation of wind turbines and associated infrastructure, which can lead to physical damage to benthic habitats and substrate.
	Noise	Mechanical noise that comes from the gearboxes and generators, and aerodynamic noise from the turbine blades.
	Pollution	Air, water and seabed contamination due to chemical substances and waste generated during the construction and operation of the plant.
	EMF emission	Cables that transmit electricity from the turbines to the onshore grid emit electromagnetic fields (EMF), which can influence behaviour and physiology of fish and other benthic organisms.

SOLAR

SECTION 4.3

Wildlife mortality and injury	Collision	Birds and insects may be unable to detect or avoid structures such as power lines and PV panels.
	Electrocution	Transmission lines and pylons are sometimes used by birds, specifically eagles, hawks, vultures, kites, falcons, storks and corvids for perching, roosting and even nesting.
Habitat loss	Habitat loss	Habitat loss occurs when the area surrounding the solar power plant has been modified to an extent that can no longer support its native species.
	Barrier effect	Blocking of the movement and seasonal migration of wildlife due to the PV panels and the associated infrastructure.
Ecosystem degradation	Habitat degradation	Change in the characteristics of a habitat due to the installation and operation of solar power and associated infrastructure, such as reduced vegetation cover, compaction of soil, reduced infiltration, increased runoff, decreased soil activity, decreased soil organic matter, and impaired water quality.
	Changes in microclimate	Changes can be induced by either a heating effect or a shading effect, and can manifest as shading, altered temperature and changed rainfall distribution.

MITIGATION MEASURES

Mitigation measures follow a hierarchical approach, based on a sequential (and iterative) application of measures to avoid, minimise, and eventually restore negative impacts. Avoidance and minimisation measures prevent or reduce impacts, while restoration measures can address any residual impacts that were not avoided or minimised. Careful implementation of avoidance and minimisation will reduce requirements for restoration measures.

Avoid

Site selection

Locating the project away from areas of high environmental and biodiversity value

Design

- **Micro-siting**
- **Technology choices** (Design features that reduce attraction of animals and insects, increase visibility to avoid collisions)

Planning & scheduling

- **Scheduling** construction to avoid sensitive periods
- **Setup appropriate plans** (Waste disposal plan, Chemical leaks and spill management plan, Sensitive lighting plans, Noise plan, pile driving protocols...)

Minimise

Abatement controls

Actions to reduce levels of pollutants (e.g., emissions of dust, light, noise), either from being produced or transmitted wider into the environment

Physical controls

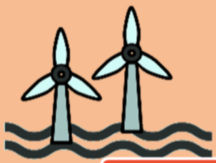
Adapting the design or operation to reduce impacts (e.g., bird flight diverters on power lines, curtailment of wind turbine operations)

Operational controls

Managing and regulating actions of people involved in the project development

MITIGATION MEASURES

SECTION 5.2



SECTION 5.3

SECTION 5.4

PLANNING

SECTION 5.2

Collision
- Micro-siting
- Re-routing of high voltage lines
- Buffer zones
- Decreasing attraction factor to bats
- Designing transmission lines to reduce the risk of collision

Electrocution
- Designing transmission lines to discourage birds to perch

Habitat loss and barrier effect
- Micro-siting / increasing spacing between turbines, or clustering of wind turbines
- Re-routing, marking or burying power lines
- Restricting extent of road network

SECTION 5.3

Collision
- Raising the height of the hub
- Painting the blade tips with bright colours
- Using adaptive light controls
- Restrictions on vessels

Habitat loss and displacement of species
- Defining routes for vessels

Noise
- Selection of materials and equipment

SECTION 5.4

Wildlife mortality and injury
- Buffer zones
- design of transmission lines and pylons to reduce risk of collision and electrocution
- Re-routing of high voltage lines

Habitat loss and barrier effects
- Micro-siting / clustering the solar arrays
- Re-routing, marking or burying powerlines

Changes in microclimate
- Type of solar PV panels

CONSTRUCTION

SECTION 5.2

Collision
- Reducing the attraction factor to bats
- Scheduling of construction activities

Barrier effect
- Scheduling of construction activities

Noise
- Alternative construction methods

Habitat degradation
- Managing and regulating contractor activity and movement
- Technical abatement measures
- Preventing the introduction and spread of invasive species

SECTION 5.3

Collision
- Scheduling of construction activities
- Acoustic Deterrent Devices (ADDs)

Noise
- Pile driving protocol
- Physical and abatement controls (types of foundations, using 'soft-start' when piling, adjusting the parameters of the pile stroke, use of sound barriers)

Pollution
- Management of waste disposal
- Prior approval of all chemicals, paints and coverings
- Frequent check and maintenance of the vessels
- Survey of the wind farm site

EMF emission
- Burying power lines

SECTION 5.4

Wildlife mortality and injury
- Scheduling construction activities
- Re-routing, marking or burying powerlines
- Removing any soil heaps

Habitat degradation
- Technical abatement measures to minimise soil erosion and sedimentation
- Mounting solar panels on pile-driven or screw-on foundations
- Managing and regulating contractor activity and movement

OPERATIONS

SECTION 5.2

Collision
- Use of deterrents
- Management and modification of adjacent habitats
- Increasing the cut-in speeds

Electrocution
- Insulation of power lines

Habitat loss and displacement of species
- Curtailment of wind turbine operations

Noise
- Alternative operational modes

SECTION 5.3

Collision
- Adjustment of the lighting
- Use of deterrents

SECTION 5.4

Wildlife mortality and injury:
- Attraction- non-polarising white tape
- Collision –bird flight diverters and parabolic (curved) mirrors
- Electrocution –adding insulation to power lines

Habitat loss and barrier effects
- Modifications to security fences
- Enhancing existing boundary features

Habitat degradation
- Revegetation and planting of previously exiting agricultural crops

Changes in the microclimate
- Introducing vegetation
- Passive cooling techniques

DECOMMISSIONING

SECTION 5.2

Collision
- Scheduling of decommissioning activities
- Reducing the attraction factor to bats

Habitat degradation
- Managing and regulating contractor activity and movement
- Technical abatement measures to minimise erosion and loss of vegetation
- Preventing the introduction and spread of invasive species

Noise
- Alternative construction equipment

SECTION 5.3

Collision
- Scheduling of decommissioning activities

Habitat degradation
- Waste management practices
- Managing and regulating contractor activity and movement

SECTION 5.4

Wildlife mortality and injury
- Scheduling of decommissioning activities.

Habitat degradation
- Managing and regulating contractor activity and movement
- Minimising habitat disturbance during infrastructure removal

3. Localisation of RAAs

3.1. Spatial considerations for the designation of RAAs

Article 15c of the revised Renewable Energy Directive (RED)[4] requires Member States to designate Renewables Acceleration Areas (RAAs) for specific renewable energy technologies as a sub-set of the areas necessary for national contributions towards the overall Union renewable energy target for 2030, which are to be mapped under Article 15b. RAAs shall be selected based on the criteria set in Article 15c to ensure that the deployment of renewable energy projects of a specific technology is not expected to have a significant environmental impact. To this end, in the designation process, Member States should prioritise areas that are already developed and in use or degraded, where environmental impacts can be expected to be lower. Member States must also exclude certain areas from RAAs designation, such as Natura 2000 sites as well as other protected and environmentally sensitive areas.

In recent years, the prolonged and burdensome permitting processes have been among the major challenges and bottlenecks for the deployment of renewable energy. To address this issue and ensure the swift approval of renewable energy projects, the revised RED introduces measures to shorten and streamline permitting procedures in all areas where renewable energy projects can be deployed. The revised RED also introduces even shorter and simpler procedures specifically within RAAs. Notably, renewable energy projects within these acceleration areas will be exempted from undergoing an Environmental Impact Assessment (EIA) under certain conditions, and stringent deadlines will be imposed on the overall permitting process. However, this streamlined approach should not compromise environmental protection. The plans outlining the RAAs must undergo a Strategic Environmental Assessment (SEA), with the aim of ensuring robust environmental safeguards. In addition, if the plans are likely to have a significant impact on Natura 2000 sites, an Appropriate Assessment (AA) of the RAAs' plan under Article 6(3) of the Habitats Directive must be conducted.

Against this backdrop, the careful localisation of RAAs is a key step of the designation process. On the one hand, the location should be chosen to avoid or minimise environmental impacts that may be identified during the SEA on the RAAs' plans. On the other hand, by selecting locations that pose fewer challenges in terms of conflicting uses – e.g. for environmental conservation or cultural heritage protection – the risk of subsequent legal disputes is mitigated.

3.1.1. Sites to be excluded

The initial step in effectively designating RAAs is to identify the areas that are not suitable to be designated as RAAs.

A first clear set of exclusions is provided by Art. 15c, par. 1.a. (ii) of the revised RED. This Article establishes that protected sites under the Natura 2000 network and areas designated under national protection schemes for nature and biodiversity conservation shall not be considered for RAAs' siting, except for artificial and built surfaces located in those areas. These include, among others, national or regional parks, nature reserves, and UNESCO biosphere reserves.

Article 15c, par. 1.a. (ii) and (iii) of the RED also excludes areas that have particular environmental characteristics, i.e. major bird and marine mammal migratory routes, as well as

[4] Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 as regards the promotion of energy from renewable sources: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413&qid=1699364355105.

other environmentally sensitive areas identified on the basis of wildlife sensitivity maps, tools and datasets. These areas may have to be identified by Member States' competent authorities to be excluded from RAA designation.

The identification of these areas is largely dependent on the availability of data and the specific environmental conditions at both national and local levels. However, some general considerations apply, and tools are available that can inform the work of the Member State competent authorities. These considerations are detailed in the two following sections, dedicated to the additional areas – besides protected areas – that Article 15c mandates for exclusion from RAAs plans, namely (i) major bird and marine mammal migratory routes, and (ii) other environmentally sensitive areas identified on the basis of wildlife sensitivity maps, tools and datasets.

3.1.1.1. Major bird and marine mammal migratory routes

Migratory routes are crucial pathways for the seasonal movement of migratory bird species and marine mammals, which play a pivotal role in their life cycles, feeding, and breeding activities. By avoiding these routes in the selection of RAAs, Member States can minimise the risks of collisions, disturbances, habitat disruption and displacement effects ensuring the preservation of migratory patterns and contributing to the overall conservation of biodiversity

However, fine, local-level, data on migratory routes and species-specific impacts of renewable energy technologies is often scarce and maintained outside centralised authorities, e.g. by research institutions or NGOs. Information and data might also be available to developers and the competent authorities as a result of past SEAs, EIAs or AAs carried out on specific projects or plans.

Collaboration between the authority leading the RAA planning process and the actors that may have relevant data is thus key to ensure that all available data are taken into account in an early stage of area identification, to avoid the emergence of environmental issues only in more advanced designation phases. This can be facilitated by an early targeted stakeholder consultation (see paragraph **Error! Reference source not found.** below). In addition, given the cross-border character of migratory routes, it is also important to ensure collaboration across different Member States and local entities.

International-level tools can provide a basis for mapping major migratory routes and relevant data. Multi-taxon data on animal movements can be found, for instance, on the platform Movebank, a free, online database of animal tracking data and other data collected by sensors on animals, coordinated by the Max Planck Institute of Animal Behaviour.

Other specific sources on birds and marine mammals include:

Birds

- Migration Mapping Tool is a database maintained by EURING, the coordinating organisation for European bird ringing schemes, that provides information of the migratory connectivity of 50 bird species in Europe, based on tracking data[5]. EURING and Movebank data on the Eurasia-Africa flyway are also combined in the Migration Atlas tool.
- Important Bird and Biodiversity Areas (IBAs), including resting and feeding habitats along migratory flyways. The database relies on mostly field counts and surveys carried out at the local level. The GIS database is maintained by BirdLife International and can be requested at https://datazone.birdlife.org/site/requestgis. There are

[5] Data visualisation at: https://app.bto.org/mmt/#15.37500|57.62500|4.00|52868|1|N|0|1|0|5|Y|Y|Y.

examples of IBAs already used for planning purposes. Italy, for instance, excludes IBAs from suitable areas for RE development[6].

- Bird Migration Map is produced by the Estonian organisations Kotkaklubi and provides visualisation of the migration path of 11 migratory birds. Although it focuses in particular on birds coming from the Baltic region, it is also relevant for countries that are crossed by the flyways.
- The Seabird Tracking Database managed by BirdLife International is the largest collection of seabirds tracking data. These data have been used to identify six main marine flyways followed by migrating seabirds between breeding and non-breeding sites. The Atlantic Ocean flyway, which includes major seabird breeding colonies, might be particularly relevant for planning offshore wind farms in EU waters.

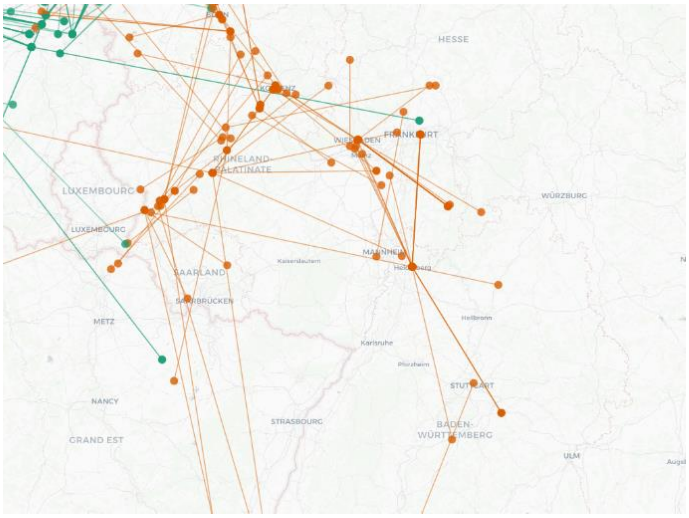


Figure 3-1 Migration flyway of the Egyptian Goose (*Alopochen aegyptica*), from the Migration Atlas

Marine mammals:

- **Protecting Blue Corridors project**, led by WWF in collaboration with several academic institutions. The Report of the project, published in 2022, identifies the main whale migratory routes. Information on data sources is also available at: https://wwfwhales.org/references.
- **Important Marine Mammal Areas (IMMAs**), as identified by the Marine Mammal Protected Areas Task Force of IUCN: https://www.marinemammalhabitat.org/imma-eatlas/ [7].
- The **ACCOBAMS - Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area –** manages a survey initiative (ASI) that collects data including on cetaceans and megafauna species through aerial surveys, boat-based visual surveys and passive acoustic monitoring surveys in the marine regions covered by the agreement. Data are available upon registration.

[6] Italy Ministerial Decree 10 September 2010, Annex 3.
[7] Full spatial database available upon request at: https://www.marinemammalhabitat.org/immas/imma-spatial-layer-download/.

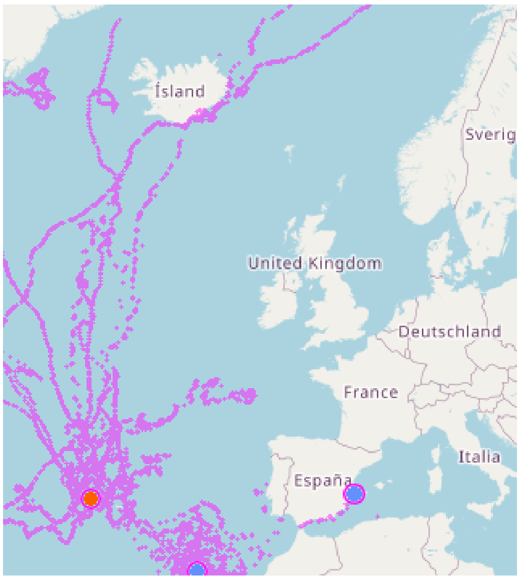


Figure 3-2 Cetacea movements in the North Atlantic region from the Movebank database

The tools mentioned can help authorities to map migratory routes for both birds and marine mammals to ensure that they are excluded from RAAs designation. It is also advisable to complement and integrate them with datasets on other sensitive areas for migratory species, such as feeding and breeding areas and distribution maps covered by the tools mentioned below under section 3.1.1.2., as well as with the location of protected sites.

Local NGOs or other actors that gather direct observation or tracking data of relevant species often have and maintain high resolution data. With specific regard to migratory birds, the network of national BirdLife's partners could offer relevant contacts in all EU Member States. Some of these NGOs have already developed tools for energy spatial planning such as the NABU study that identifies potentially suitable areas for offshore wind energy from a nature conservation perspective in the German North and Baltic Seas, which includes relevant flyways and marine mammal distribution maps.

3.1.1.2. Other sensitive areas to be determined using available tools and datasets including sensitivity mapping

In addition to excluding Natura 2000 sites and areas designated under national protection schemes for nature and biodiversity conservation, and major bird and marine mammal migratory routes from RAA designation, Article 15c of the revised RED mentions other areas to be excluded identified on the basis of sensitivity maps and all appropriate and proportionate tools and datasets. This section covers other environmentally sensitive areas that could fall into the above-mentioned category.

The main challenges that are likely to be encountered when planning exclusions based on environmental sensitivity are related to defining sensitivity with regard to national and local specifics, and data availability.

Sensitive areas are, in general, areas where intensive renewable energy development – as foreseen within RAAs – would entail a significant impact on biodiversity, ecological dynamics or ecosystem services provision.

The European Commission already published a few guidance documents that can guide Member States in the process of wildlife sensitivity mapping relevant for locating renewable energy installations.

The publication "The Wildlife Sensitivity Mapping Manual: Practical guidance for renewable energy planning in the EU"[8] is a guidance document published in 2020 by the European Commission concerning wildlife sensitivity mapping approaches in the context of renewable energy development. It is a comprehensive document with extensive references to external sources providing examples and data.

The 2020 publication "Guidance document on wind energy development and EU nature legislation" is also relevant in this regard as it provides guidance and useful examples of wildlife sensitivity mapping with specific regard to wind projects siting to minimise effects on biodiversity and protected areas.

With specific regard to marine sensitive areas, the Marine Megafauna Conservation Toolkit, produced by BirdLife International describes tools and methods that can be used by public authorities to identify important sites for marine megafauna, including support on how to turn complex animal tracking data into outputs for effective conservation.

The mapping of sensitivity areas can be hampered by the lack of available and/or robust data. The competent authorities should thus engage from the early stages of their RAAs mapping process in collecting relevant datasets. These might include spatially oriented datasets, such as land cover datasets, ecological integrity maps, habitat and distribution maps of endangered species, and maps of ecological corridors. Some of this data might be maintained by NGOs or research institutions, hence the importance of identifying them and including them early on through stakeholder consultation. Spain, for example, used several mapping tools developed by SEO/BirdLife and the WWF to develop territory classification maps regularly used in EIAs for RE projects at both the national and regional levels.

Examples of sensitive areas, which need to be considered on the basis of appropriate and proportionate tools as mentioned in revised RED Article 15c(1)a(ii) and (iii) include:

- **Sites important for birds**. Wind turbines can be a concern for bird species. Locating RAAs close to important breeding, feeding or nesting grounds for birds, for instance, can increase the risk of collisions and amplify environmental impacts. For these reasons, some Member States are already working on integrating birds' sensitivity areas into RE development planning, when these are not already included in the Natura 2000 network of protected sites. The abovementioned database of Important Birds and Biodiversity Areas (IBAs) identified by BirdLife is a useful tool in this regard. Several IBAs may be designated as protected areas, thus falling by default under the category for exclusion. In addition, the EUROBIRD Portal (EBP) provides a common data repository based on aggregate data from online bird recording portals from across Europe, currently covering 29 different countries. Relevant data might also be available already to national environmental authorities. There are also several LIFE projects which deal with birds habitats' conservation, so the competent authorities can reach out to the organisations managing these projects to obtain specific data. The citizen-science programme NestWatch also provides an open-access dataset of nesting sites. In some cases, breeding sites and breeding periods are not publicly available for security reasons but can be requested from the database owner. NGOs in many countries are also developing mapping tools whose data can be integrated into the planning process. For example, LIPU in Italy developed a country-wide bird sensitivity map covering 44 species affected by onshore wind and 26 species affected by offshore wind projects[9]. In Austria, BirdLife Austria has developed zoning maps for three provinces, by first identifying the areas that host the most sensitive species, then

[8] European Commission, Directorate-General for Environment, Allinson, T., Jobson, B., Crave, O. et al., The wildlife sensitivity mapping manual – Practical guidance for renewable energy planning in the European Union, Publications Office, 2020.
[9] LIPU, Impianti eolici – le mappe della lipu per evitare le aree sensibili per gli Uccelli, http://www.lipu.it/news- i. The article includes a link to the map.

applying minimum distances from the nesting site/centre of territory of those species. Exclusion of an area is suggested when the minimum distances of three relevant species are overlapping.

- **Sites important for bats**. Mapping important bat colonies and their foraging habitats is key to avoiding impacts that RE development might have on bat species, with regard to both wind and ground-mounted solar PV plants. In this respect, it is worth noting that most EU Member States are part of the UNEP/EUROBATS Agreement on the Conservation of Populations of European Bats. EUROBATS has Intersessional Working Groups, some of which are potential sources of data and work on relevant topics for RES development (e.g. Working Groups on Wind Turbines and Bat Populations; Conservation and Key Underground Sites; Potential Impact of Solar Power Plants). Careful consideration of bats sensitivity areas might be particularly relevant when the RAAs planning is considering mines, which are explicitly included among the priority areas for RAAs in the revised RED.
- **Habitats of species sensitive to solar and wind technologies**. Species distribution maps should be gathered with regard to species sensitive to solar or wind, with particular focus on endemic species, or species whose status is considered endangered or vulnerable, or whose conservation is prioritised under national legislation, the EU Birds and Habitats Directive, or the Bern Convention. Other relevant species that might be considered are those listed in the IUCN Red List of Threatened species, for which IUCN maintains a database of species distribution. Tools such as the abovementioned platform Movebank can also be used to gather relevant data.
- **Prospective protected areas or other important areas for biodiversity**. This category includes natural areas identified as prospective protected areas or other important areas for biodiversity, for which a formal designation under a protection regime has not taken place. If a decision has been taken for their designation as protected areas but the administrative steps are ongoing, these areas should be treated as protected and thus fall under the exclusion category for RAA designation. This category may also include areas that have been, or will be, identified as important for biodiversity in the context of achieving the EU and international biodiversity targets. In some Member States, the Natura 2000 network is still incomplete – especially in marine areas[10]. However, in the coming years, Member States will need to identify additional protected sites for biodiversity conservation to contribute towards the 30% protected area target under the 2030 Biodiversity Strategy and the targets under the CBD Kunming-Montreal agreement. Their identification may proceed in parallel with the designation of RAAs. These areas could include, for example, additional important habitats of species listed in the Nature Directives, areas supporting ecosystems connectivity, future climate refugia or areas in need of restoration. Data and sites' identification decisions in this context should be thus integrated, as they become available, into the process of RAAs localisation. In this regard, the European Commission published a guidance document for the identification and designation of additional protected areas from which criteria can be drawn to minimise the risk of overlapping with RAAs plans[11].

  Ecological corridors could also be considered by Member States under this category. These are areas that are particularly important to avoid habitat fragmentation, which is one the leading causes of biodiversity loss in Europe. One of the key goals of the 2030 EU Biodiversity Strategy is the development of a Trans-

[10] For example, the region of Galicia in Spain has a relatively poor coverage of Natura 2000 and other protected areas, with only 12% of its land surface protected. Designation of MPAs is also ongoing in several countries including Ireland and Croatia.

[11] European Commission, Criteria and guidance for protected areas designations, Commission Staff Working document, SWD(2022) 23 final. Available at: https://environment.ec.europa.eu/document/download/12d0d249-0cdc-4af9-bc91-37e011620024_en?filename=SWD_guidance_protected_areas.pdf.

European Nature Network (TEN-N) that addresses gaps in the coverage of habitats and species and brings added coherence to the existing network of Natura 2000 and nationally-designated protected sites. The Horizon Europe funded project NaturaConnect is an example of action aimed at identifying such corridors. In France, a national map of ecological corridors (Trame Verte et Bleu) has already been developed based on regional data. In the French case, these areas are not a priori excluded from RAAs but should be taken into account by local authorities in their planning process[12].

- **Wetlands** covered by the Ramsar Convention, if not already included in the Natura 2000 network or national protection schemes.

In some Member States and regional contexts, innovative comprehensive tools are being developed to integrate ecological modelling into the spatial planning processes, which could be regarded as best practices. Examples include:

- In Flanders, Belgium, the Biological Valuation Map (BVM) is a uniform field-driven survey of the land cover and vegetation with indication of the related biological valuation.
- The Flanders region in Belgium also developed wind farms sensitivity maps for birds and bats for assessing areas where siting wind turbines may pose a risk to bird or bat species. This tool classifies region into four risk categories.
- In the Netherlands, the Digitwin North Sea project provides open access to several datasets which are relevant for spatial planning in the North Sea, such as on bird sensitivity.
- In Belgium, the BWZee atlas provides a biological valuation map for the Belgian continental shelf, covering seabirds, macrobenthos, epibenthos and demersal fish.
- Also in Belgium, the Belgian Marine Data Centre collects relevant data for spatial planning, including observations of marine mammals, and stores data from the monitoring programme that spans the Belgian part of the North Sea as part of the MSFD and Natura 2000 monitoring requirements.
- ODIMS, the Data and Information Management System of the OSPAR[13] Convention (Convention for the protection of the Marine Environment of the North-East Atlantic) provides datasets, including in GIS format, on biodiversity and ecosystems of the North-Atlantic region.
- The European Marine Observation and Data Network (EMODnet) is a platform supported by the EU integrated maritime policy where different organisations make marine data publicly accessible. It also includes data on seabed habitats in Europe (EUSeaMap).
- Spain has developed a zoning tool of the environmental sensitivity of the whole national territory. It consists of two layers of information (one for wind energy and one for PV) that show the value of the environmental sensitivity index existing at each point on the map, and the associated environmental indicators.

Finally, it is important to note that artificial and built surfaces located in environmentally sensitive areas – such as transport infrastructure and parking areas – remain available for inclusion in RAAs.

[12] Office français de la biodiversité (OFB), Annex technique de l'outil cartographique pour identifier les aires d'accélération des énergies renouvelables terrestres. Available at: https://naturefrance.fr/sites/default/files/2023-07/annexe_techniques_visualiseur_ENR.pdf.
[13] Mechanism by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic, named after the Oslo and Paris Conventions.

Box 1 – Best practice from Croatia: Zadar County pilot project "Integrating Renewable Energy Planning in Southeast Europe"

Zadar County in Croatia served as a pilot project for an integrated RES planning approach – focusing on wind and solar – in collaboration with The Nature Conservancy and the Hrvoje Požar Energy Institute (EIHP). The methodology developed under this pilot project is currently informing the wider study on candidate areas for RAAs at the national level.

The pilot project implemented a stepwise approach to sensitivity mapping:

(i) First, areas with legal constraints were identified that cannot be used for wind and solar siting (**exclusion zones**);

(ii) Second, areas were identified which are potentially highly vulnerable to the establishment of wind and solar plants (**very highly sensitive zones**);

(iii) Third, the remaining areas were evaluated against a set of environmental as well as socio-economic indicators using a multi-criteria analysis (MCA). Based on the result of the MCA, areas were categorised as **low, medium or high sensitivity zones**.

The resulting maps of sensitivity were then compared to the **suitability areas** for solar and wind, based on natural potential and technical requirements, to identify areas that have low levels of sensitivity and are also potentially suitable for the targeted RES technologies.

Detailed information on the approach and methodology can be found in the pilot project report.

3.1.2. Identifying priority areas

The RED (Art. 15c, par. 1.a.(i)) includes a non-exhaustive list of artificial and built surfaces that must be prioritised for RAA designation. Some of those surfaces are of a reduced size, allowing for the installation of solar panels dedicated mainly to self-consumption or small-scale production (i.e. rooftops, parking areas and farm buildings). It is important to note that Article 16d of the revised RED introduces a simplified permitting procedure, shorter than the procedure for RAAs, for solar energy installations on artificial structures, which includes rooftops, car parks, farm buildings, and any other existing artificial structures where solar energy equipment can be installed.

The present guidance focusses on ground-mounted renewable energy installations and therefore explores the potential to designate renewable acceleration areas in specific examples listed in Article 15c:

- **Transport infrastructure and its direct surroundings.** The areas dedicated to major linear transport infrastructure (e.g. motorways, railways) are usually highly developed and have a low environmental value, although a case-by-case assessment might be needed. Nevertheless, in some Member States, there are rules that prevent locating RE plants close to transport infrastructure for safety reasons. These rules are in some cases obsolete in light of technological advances. An assessment of such existing barriers by the competent authority might therefore be needed before including transport infrastructure within RAAs' plans (see also section 3.2.2. below). Installation of RE plants – both wind and solar - along linear transport infrastructure may also increase the visibility and positive public perception and understanding of the need for renewable energy, especially where plants are associated with installed charging points for electric vehicles, e.g. at service stations. Ports are also potential RAA sites. Their high energy consumption levels and existing available infrastructures make them good candidates to accommodate RE plants. Both solar and wind technologies might be suitable, depending on local conditions, to provide locally generated energy to be used for ports' energy needs, such as equipment electrification. For example, the companies located in the port of Antwerp-Bruges produce renewable energy locally with solar panels and wind turbines, contributing to providing power for energy-intensive port activities, terminals, and ships[14].

- **Waste sites.** While the number of active landfills is decreasing, all EU Member States have capped landfills on their territory that need to be monitored and maintained for a long period of time. Installing solar plants on landfills offers an opportunity to use such areas in a productive way, which otherwise have very limited options for redevelopment.
- **Industrial sites.** RAAs in industrial sites can increase the efficiency of the electricity system by locating generation close to areas of high consumption. Potential synergies with existing infrastructure also make industrial sites suitable for RE development. The RE development might also increase the attractiveness of these sites for environmentally aware investors. Both solar and wind technologies can be effectively deployed in industrial sites, depending on the local characteristics.
- **Mines.** Decommissioned mines are often large degraded areas that provide opportunities for RE development. A large project in this regard is under development in Germany to build solar and wind plants with a capacity of up to 7 GW on the area of former coal mines by 2030[15].
- **Artificial inland water bodies, lakes or reservoirs.** Artificial water bodies – such as bodies created by damming, artificial lakes and reservoirs, irrigation storage ponds and canals - usually have a low value for biodiversity and minimise trade-offs with other land uses. A case-by-case assessment of their environmental value shall nevertheless be provided, especially for older water bodies that might have developed a higher value ecological role over time. Among artificial water bodies, concrete irrigation canals are especially good candidates for solar power production. Such canals often form a large network in the rural areas of many Member States and solar panel coverage can contribute to both energy production and water saving, which is a particularly pressing issue in arid rural areas. Several solar projects on canals are under development in the EU. For example, the 12 MW Canal de Provence floating solar PV plant is projected to be installed on a canal system bringing water to 110 municipalities in southern France. Currently at the permitting stage, the project construction is expected to start in 2024. Once operational, it will generate a total of 19 GWh per year[16]. Similar projects are under development in Spain, for example on the Navarra Canal, one of the country's largest irrigation canals where a 160 MW plant is being developed[17]. It is also worth noting that floating PV capacity on hydropower reservoirs could be integrated into the existing grid infrastructure of the hydropower facilities, including using the hydropower element as "virtual battery" leading to grid stabilisation and water saving.
- **Urban wastewater treatment (WWT) sites.** Their large open spaces, high electricity demand and high load factor due to long operating hours make them good candidates for solar PV systems, possibly in combination with a CHP using biogas. Solar thermal can also be used in several WWT processes, such as for heating digester tanks or sludge drying beds. Wind energy technologies are

[14] Port of Antwerp Bruges, Climate and energy transition.
[15] Weforum, This historic mining belt in Europe is planning to become a green energy hub. Here's how
[16] PV-magazine, France's Provence Canal to host 12MW of solar.
[17] PV-magazine, Project to deploy 160 MW solar array on Spanish canal moves forward.

however less suitable, as urban WWT sites are generally located in urban or suburban locations.

- **Degraded land.** Degraded land such as brownfields and agricultural land with deteriorated or no productive capacity may be unsuitable for agriculture or other productive uses due to, for example, poor soil quality, erosion or contamination. This often occurs in open areas with limited vegetation, suitable for RE development. On the other hand, these areas may have restoration potential. Prioritising these areas for RAAs' localisation can bring into use otherwise unproductive areas without competing with agricultural land use, and might also provide benefits in terms of environmental restoration of the land and soil health if such objectives are sought together with renewable development. If these areas are selected for RAAs designation, synergies with nature restoration should be sought wherever feasible.

Other potential priority areas for RAAs include:

- **MSPD identified areas**. For offshore plants, the areas that have been already identified as suitable to the production of energy from renewable sources under the Maritime Spatial Planning Directive (MSPD) can be considered as priority areas for RAAs designation provided that the conditions under Article 15c are fulfilled. This would enable synergies with the environmental assessments carried out as part of the MSPD implementation process.
- **Marine areas with poor seafloor conditions and low habitat value.** The Marine Strategy Framework Directive (MSFD) includes seafloor integrity as an indicator of Good Environmental Status (GES). Areas with degraded seafloor could be prioritised for the location of offshore energy installations to minimise impact on healthy habitats, provided that compatibility with achieving GES is ensured. This could also provide synergies with restoration activities[18].
- **End-of-life offshore platforms.** Many oil and gas offshore structures are expected to reach the end of their productive life in the coming decades. According to OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations, leaving such installations in place wholly or in part within maritime areas is prohibited. However, derogations can be considered when there are significant reasons supporting an alternative disposal that includes leaving the structures fully or partly in place[19]. In these cases, their conversion to RE production can be a viable option resulting in a positive environmental effect with respect to standard decommissioning[20], although other studies were less optimistic on their potential[21].

3.1.3. Other considerations

Other EU legal instruments, international and national provisions may also prove pertinent in refining the geographical scope of RAA candidates.

3.1.3.1. Nature restoration

Encouraging the integration of renewable energy deployment with nature restoration efforts presents valuable opportunities, including in the implementation of the Nature Restoration

[18] For example, WWF Denmark and Ørsted set up a collaboration to support the decreasing cod population by installing 3D-printed reefs in the otherwise barren seafloor around wind turbines https://orsted.com/en/media/news/2022/06/13654370.
[19] OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations, https://www.ospar.org/documents?v=6875.
[20] Leporini, M. et al., Reconversion of offshore oil and gas platforms into renewable energy sites production: Assessment of different scenarios. Renewable Energy, 135 (2019) 1121-1132.
[21] European Commission, Directorate-General for Energy, Van Nuffel, L., Cihlarova, P., Forestier, O. et al., *Study on decommissioning of offshore oil and gas installations – A technical, legal and political analysis – Final report*, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2833/580313.

Law[22]. Solar power generation can be combined with environmental stewardship and agro-ecological practices on brownfields, former mining sites, or degraded land. This approach not only facilitates the deployment of renewable energies but also contributes to vital biodiversity advantages by restoring the functionality of degraded soils. Research also highlights that solar parks can be planned and managed in ways that directly benefit pollinator species, for example by providing foraging, nesting and breeding resources, increasing semi-natural habitat in the landscape and promoting connectivity, and generating microclimatic variations[23]. In the marine environment, wind turbines can harbour species that have been negatively affected by the impact of fishing practices on the seabed, such as shellfish and benthic animals[24].

Coordinating planning for restoration activities and renewable energy deployment including RAA designation can promote spatial planning choices and project design and implementation that supports both objectives and enables potential synergies.

In the framework of the Nature Restoration Law, restoration activities and the deployment of renewable energy projects may be combined wherever possible, including in RAAs and dedicated grid infrastructure areas. Restoration measures adopted as part of renewable energy projects could be designed in a way that counts towards the fulfilment of restoration targets (e.g. restoration and re-establishment of certain habitat types and habitats of species, restoration of pollinator populations and agricultural ecosystems). Member States should coordinate the development of their national restoration plans with the mapping of areas that are required to meet their national contribution towards the 2030 renewable energy target and, where relevant, with the designation of renewable acceleration and dedicated grid infrastructure areas, while ensuring that the functioning of those areas and permit-granting procedures remain unchanged. Consequently, wherever possible, the development of RAA plans should be coordinated and ensure synergies with the national restoration plans.

3.1.3.2. Constrained and high trade-off zones

The strategic avoidance of areas with high trade-off potential with other land uses and areas subject to specific legal constraints can reduce the administrative burden related to the designation process – notably, the SEA and AA, if applicable, that must be carried out on RAAs' plans. These areas are not excluded under the revised RED but their careful consideration during the RAAs' designation process can also minimise the risk of subsequent legal disputes that could impede the timely approval and implementation of the RAAs' plans. They include:

- **Buffer areas around Natura 2000 sites or other protected areas, and sites that can have an impact on them.** In general, it is advisable to keep RAAs beyond a minimum distance from protected sites to avoid potential impacts on sensitive areas and species. The distance requirements should be determined on a case-by-case basis depending on the ecosystems protected. As a general reference, in 2015 the Working Group of German State Bird Conservancies published a set of Recommendations for distances of wind turbines from important areas for birds. This identified a distance of 10 times the turbine height (or at least 1200m) as an advisable minimum from protected areas for species sensitive to wind turbines. Inclusion of such buffer areas in a RAA plan would also require, in most cases, a specific Appropriate Assessment under Article 6 of the Habitats Directive. In addition, the generally higher risk of environmental impacts for RE developments close to sensitive areas increases the risk of legal disputes against approved projects.

[22] https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en
[23] Blaydes, H. et al., (2021) Opportunities to enhance pollinator biodiversity in solar parks, Renewable and Sustainable Energy Reviews, Vol. 145, 111065. https://doi.org/10.1016/j.rser.2021.111065.
[24] Wageningen University & Research, Offshore wind energy: Opportunities for nature restoration and biodiversity.

- **Valuable agricultural land.** Article 15c of the revised RED requires prioritising degraded land not usable for agriculture, which does not mean agricultural land is completely excluded but trade-offs need to be considered, as well as synergies and compatibility with the pre-existing uses of the area. Some Member States have specifically excluded these areas from RAA designation. For example, the RAAs mapping exercise carried out in Portugal and the pilot project run in the Croatia Zadar County excluded the arable land that was identified as particularly valuable under the currently applicable legislation and planning from accelerated RES deployment.
- **Historical and cultural heritage sites.** UNESCO sites and other cultural heritage sites are likely to be subject to specific restrictions of use in national legislation. These areas also include underwater heritage that might be covered by the legislation transposing the Maritime Spatial Planning Directive. The participation of the authorities entrusted with the protection of cultural heritage in the process of RAAs identification and designation is thus key to minimising conflict with those sites.
- **Water protection.** Legal constraints might exist relating to the legislation transposing the Water Framework Directive (WFD)[25] and Floods Directive[26] concerning areas relevant for flood risks and areas requiring special protection of their surface water and groundwater. Some Member States such as Spain and Portugal, as well as the pilot project for Zadar County in Croatia, have excluded these areas from RAA designation. In these cases, relevant zones for mineral and natural water were also excluded. France, on the other hand, considers flood areas and protected areas under the WFD as areas that are not legally excluded from RE development acceleration but for which special consideration is required due to their environmental sensitivity[27].
- **Marine protection.** Constraints on the use of marine space might be imposed by the national transposition of the EU Marine Strategy Framework Directive (MSFD). Spatial protection measures under the MSFD – e.g. marine protected areas (MPAs), measures for the protection of flyways – would fall under the areas designated under national protection schemes for nature and biodiversity conservation, to be excluded from RAAs designation (see section 3.1.1 above). The Member States' programme of measures can include additional provisions – such as temporal limitations to RE plants operations to preserve ecological functions – that might be worth considering when deciding on the localisation of RAAs.

3.2. Enabling conditions

3.2.1. Conditions supportive to effective RAAs designation

The following conditions have been found to be conducive to a smooth and effective designation of RAAs.

- **Clear identification of roles and responsibilities.** When identifying the authorities in charge of the designation of RAAs, Member States will choose either a centralised or decentralised approach depending on national circumstances, such as the national constitutional framework and the size of the country. A centralised approach would see a single authority in charge of the entire process at the national level, including a directive role over local authorities that may play a supporting role. On the other hand, a more decentralised approach would involve entrusting the competence for the designation of RAAs to local authorities, possibly including some shared

[25] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.
[26] Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks.
[27] Ibidem.

responsibilities across administrative levels. In both cases, it is necessary that Member States clearly allocate responsibilities and powers, so that all relevant bodies can understand how they fit into the process, and act accordingly.

- **Uniform approach at national level.** In some Member States, local authorities have a wide competence regarding planning and permitting. Having clear definitions, rules and procedures standardised at the national level – in accordance with the Member State's constitutional framework – is expected to ease the effective implementation of RAAs, and minimise the risk of scattered planning and lack of clarity for investors and developers. This is especially important for the identification of exclusion areas, the procedural steps for the plan's designation process – including stakeholder engagement – and the choice of mitigation measures.
- **Availability of environmental and landscape data.** The competent authorities should prioritise the collection of relevant available environmental data from all reliable sources to inform the RAAs designation process and identify potential data gaps. The integration of different databases is good practice conducive to an effective designation process. This is particularly important when the responsibility to identify RAAs is entrusted to local entities, which might need support to ensure a sound and harmonised methodological approach, for example, for environmental sensitivity mapping. In this regard, France, which opted for a decentralised designation of RAAs, makes a comprehensive GIS mapping tool[28] available to local entities where exclusion zones and zones requiring particular attention are identified and mapped on the whole national territory.
- **Developing scenarios to refine mapping of suitable areas for RAAs.** The final RAAs will be a subset of the areas identified under Article 15b, par. 1 of the revised RED - delineating the areas necessary for national contributions towards the 2030 renewable energy targets. On the basis of the initial map, areas that must be excluded from RAAs (protected areas, migratory routes and other areas identified on the basis of sensitivity maps and other tools) and priority areas can be identified. To further refine the mapping and adapt them to the country's specifics and legal landscape, developing scenarios might be helpful to support decision-making. Each scenario could describe different levels of exclusion of constrained or high trade-off areas under point 3.1.3.2 above (e.g. different distances from protected areas, all or a set of identified ecological corridors, etc.). The competent authority can then assess and weigh the different scenarios in comparison to:
    - the location and extent of priority areas as defined by the competent authority;
    - the maps detailing energy potential for the relevant technologies;
    - the requirements concerning surface and capacity necessary to achieve the renewable energy targets.

  On this basis, the option that maximises the inclusion of priority areas and energy potential, and ensures that enough surface is included in the RAAs, while minimising the inclusion of constrained and high trade-off zones should be retained.
- **Monitoring impacts and review of the plan.** High quality environmental data are crucial for the RAAs designation process. However, their availability and accuracy vary among Member States. Establishing a clear procedure for monitoring unexpected environmental impacts resulting from the RE deployment in RAAs can anticipate potential damage and its consequent impact on RAA operations[29]. Should significant unforeseen impacts be detected, a review of the RAA plan could be considered for providing additional mitigation measures, and integrated into the

[28] Available at https://naturefrance.fr/actualites/energies-renouvelables-un-outil-pour-eclairer-les-communes-sur-les-zonages#:~:text=zones%20exclues%20des%20aires%20d'acc%C3%A9l%C3%A9ration%20de%20l'%C3%A9olien%20terrestre,211%2D1%20et%20L.

[29] See for example the monitoring program of the effects of the installation of wind turbines on the marine ecosystem in Belgium. Details available here: https://odnature.naturalsciences.be/mumm/en/windfarms/.

periodic review mandated by the revised RED in Article 15c, par. 3. Defining a specific timeframe for the review and incorporating updates on available environmental data and impacts would enhance the adaptability of the designation process, ensuring that environmental considerations are monitored and addressed. In addition, unforeseen impacts could emerge from the individual project's screening processes. It is worth noting that individual projects, while exempted from an EIA, shall still be subject to a screening process under Article 16a(4) of the revised RED. The screening process aims to identify if the project is highly likely to give rise to significant unforeseen adverse effects in view of the environmental sensitivity of the geographical areas where it is located, which were not identified during the SEA or the AA carried out on the RAA's plan. If the project is screened as highly likely to give rise to significant unforeseen effects, an EIA is required for the specific project, and the relevant environmental data should be fed into the review of RAA's plan. If, following some time after the establishment of an RAA, it is observed that more projects are gradually called in for an EIA, this might be a good indication to review the RAA plan and update the mitigation rulebook.

- **Early stakeholder engagement.** Early involvement of relevant stakeholders is crucial right from the initial mapping of RAAs candidate areas. This proactive engagement helps to ensure effective data gathering, identify potential issues and challenges, and allows for the early development of a robust risk mitigation strategy. By fostering collaboration with diverse stakeholders at the outset, the planning process gains valuable insights, promotes transparency and public support, and lays the foundation for a well-informed RAAs designation process (see below, paragraph **Error! Reference source not found.**).
- **Inter-institutional and international collaboration.** The designation of RAAs necessitates effective collaboration across diverse policy domains such as spatial planning, renewable energy deployment, and nature conservation. Similarly, collaboration is necessary between different institutional levels (e.g. national/federal, regional, municipal). Establishing robust collaboration between the different concerned authorities within each Member State is of paramount importance right from the initial stages of the RAA designation process. It is crucial to ensure that different administrative entities work cohesively to enhance the overall efficiency of the process. Indeed, many stakeholders pointed out that poor collaboration and miscommunications between authorities is a common challenge in RE development. Similarly, collaboration might be needed between competent authorities in different Member States at several stages of RAAs' designation, such as the identification of relevant migration routes and cross-border environmentally sensitive areas or the assessment of RAAs impacts on other Member States in the context of the SEA process.
- **Utilisation of identified suitable areas.** Efficiencies should be sought by integrating the mapping of those areas that have been already designated as suitable for the accelerated deployment of one or more types of renewable energy technology into the RAAs. This approach should ensure compliance with all conditions specified under Article 15c, par. 4 of the revised RED. Similarly, the areas identified as suitable under the Marine Spatial Planning Directive's transposition instruments should also be prioritised for consideration as RAAs, provided that all criteria set out in the revised RED are met.
- **Multiple uses of the land.** Synergies should also be sought between land use for renewable energy production and other purposes. This aims to maximise efficiency and minimise overall impacts on open landscapes and natural areas. For instance, as previously mentioned, RAAs could contribute to restoration goals in brownfield or degraded agricultural areas, and they could optimise land usage by prioritising sealed land and artificial structures, such as parking areas.

Box 2 – Best practice from Portugal: Scenario approach

The Working Group for the Definition of Renewable Energy Acceleration Areas (GTAER)[30] has been tasked by the Ministry of Environment and Climate Action to identify areas with lower environmental and heritage sensitivity for the location of RAAs. The GTAER developed a methodology based on the following main steps:

- Data gathering to identify exclusion areas;
- Development of GIS datasets and algorithm to subtract from the map of continental Portugal the polygons to be excluded;
- Development of draft maps of potential candidate RAAs and scenarios.

Five different scenarios were developed. These scenarios represent different policy options which differ in terms of whether or not a number of areas subject to controversial constraints or trade-offs were excluded from the potentially suitable sites for RAAs. These included buffers of 100m width from residential and mixed-use buildings, porous aquifers, as well as agricultural and ecological reserves.

This approach was used to test the respective "weight" of the most controversial exclusions under the different scenarios. In addition, it provided options to be compared with the land area needed to meet the renewable energy targets of the country.

3.2.2. Factors which hinder the RAAs designation process

We list below some key considerations that have been found, or are expected, to hamper the smooth designation of RAAs and should thus be taken into account by Member States.

- **Data scarcity and inconsistency.** The availability, quality and integration of data concerning environmental sensitivities, land cover and land use are critical limiting factors that may impede the process of locating and designating RAAs. Reliable spatial and environmental databases in compatible formats, integrated across relevant spatial scales serve as a knowledge basis for the whole process. Therefore, it is particularly important to gather all available data in the early stages of the process through extensive collaboration with public entities, experts and stakeholders who can contribute the necessary data.
- **Fragmentation due to decentralised designation process.** The experience of some Member States with a decentralised approach for identifying suitable areas for RE development highlighted the difficulties that local authorities might encounter in the process of RAAs designation. Difficulties with decentralised processes relate in particular to the resources needed for sensitivity mapping and prioritisation, in terms of data availability as well as methodological guidance. Such difficulties risk leading to a fragmented landscape where the identification of exclusion zones and prioritisation follow different methodological approaches across the MS, which is likely to cause inefficiencies and reduce industry and public support for the RAAs designation process.
- **Existing legal and regulatory barriers.** In some cases, Member States have rules in place that limit the deployment of RE to certain land use classes (e.g. only industrial areas) or exclude some areas such as buffer zones around residential areas and transport infrastructure. In this regard, it is important that the competent authority examines the legal and regulatory landscape before starting the RAAs mapping process. In some cases, the limiting regulations in place might be obsolete, arising

[30] Order 11912/2923, available at: https://diariodarepublica.pt/dr/detalhe/despacho/11912-2023-224661349.

from safety concerns or concerns regarding the visual or noise impacts that are not aligned with the current RE technologies anymore. The collation and an analysis of such constraints is thus necessary to allow sufficient time to revise, adapt or amend the relevant laws and regulations where appropriate, or to adjust the RAAs plans to avoid these barriers emerging at later stages of the RAAs designation process.

- **Potential trade-offs with other land and marine uses.** Trade-offs with other land and marine uses are often the basis of legal disputes and the cause of delays in RE development processes. To minimise the impact of trade-offs on RAAs designation, particular attention should be devoted to the mapping process, with the aim of mitigating the risk of environmental impacts or conflicts with other human activities as much as possible (see paragraph 3.1.3 which provides an overview of relevant considerations in this regard). For example, establishing RAAs in marine areas already identified as suitable for renewable energy development under the Maritime Spatial Plans would facilitate the Strategic Environmental Assessments required for RAAs plans. Similarly, the inclusion of areas within RAAs that are adjacent to Natura 2000 protected sites, or may impact these sites, should be carefully assessed, as their inclusion is likely to trigger the need for an Appropriate Assessment under Article 6 of the Habitats Directive with the related administrative burden, as well as a higher risk of legal disputes against the approved RAAs plans.

Box 3 – Best practice from France: Removing limitations on RE development along motorways

In France, land close to motorways and major roads was not used for other purposes, although it was estimated to have an overall PV potential at 150-200 MW per 1000 km of motorway, totalling a potential of 1800 to 2400 MW for the 12000 km of motorways in the country. However, Article L. 111-6 of the French urban planning code prohibited the construction and installation of PV plants outside urban areas within a 100m buffer on either side of motorways and intersections, and within a 75m buffer other roads classified as major traffic arteries. To overcome this barrier, Law n. 2023-175 of 10 March 2023 for RE acceleration (ApER), amended the urban planning code to introduce an explicit derogation from the ban on construction on buffer areas for solar energy infrastructure, PV plants or solar thermal plants.

Box 4 – Best practice from Estonia: Identifying and removing barriers

Estonia’s Recovery and Resilience Plan identifies wind energy generation – and offshore wind in particular – as the most efficient and effective solution to achieve the targets of the strategy “Estonia 2035” in terms of transition to climate-neutral electricity generation. However, the Plan recognises that the deployment of new wind turbines (>200m in height) is limited by national regulation setting strict height restrictions for air traffic control. Investing in a new radar system compatible with new wind turbines technology is thus identified and planned as a key step to boost green energy production. The deployment of the new radar system is expected in 2026, followed by the removal of the height limitation for wind energy generation in the first quarter of 2027, which will allow the installation of new generation wind turbines.

3.3. Stakeholder engagement and public participation

3.3.1. Benefits

Engaging stakeholders and seeking the participation of the public at the early stages of RAAs' planning – before the formal SEA and AA consultations on the plan(s) are put in place – could benefit the process of identifying and designating RAAs for several reasons.

By involving stakeholders from the outset, potential issues can be identified during the development phase of the plans, which allows for timely adjustments and minimises the administrative costs that may escalate in later stages. This also significantly reduces the risk of legal disputes challenging the final plans. Early consultation not only facilitates a more comprehensive understanding of concerns and perspectives but also fosters a collaborative approach in addressing challenges. This proactive engagement ensures that plans are better-informed, more likely to garner support, and are less susceptible to delays or obstacles during the approval process.

In addition, early stakeholder engagement is instrumental in data gathering. Environmental data, crucial for RAAs' planning, are often maintained by NGOs or research institutions. Collaborating with these stakeholders allows planners to access valuable datasets that contribute to a more thorough understanding of the key environmental issues and allow for the development of robust sensitivity maps.

Engaging the public in the mapping process helps ensure that the community's perspectives are considered. This increases the likelihood of public acceptance for RAAs and the RE projects that will be developed in those areas. In this regard, it is worth noting that Article 15d of the revised RED requires Member States to identify the public affected or likely to be affected by the RAAs plans and ensure public participation in their designation process.

3.3.2. Engagement methods that can be considered across the stages of RAAs designation

Several tools might be used to engage stakeholders from the early stages of the planning exercise. Several possible tools are mentioned below, which can also be combined into a comprehensive consultation strategy:

1. <u>Stakeholder mapping</u>

The mapping exercise involves identifying in advance and categorising all relevant stakeholders that might be affected by the RAAs designation – such as local communities, land owners, electricity grid operators, renewable electricity project developers and investors' associations and representatives, NGOs – as well as organisations that might have access to relevant data, such as those needed to develop sensitivity maps (e.g. environmental NGOs, academic experts).

2. <u>Interinstitutional cooperation</u>

Interinstitutional cooperation emphasises collaboration between the competent authorities for the RAAs designation process and other relevant public institutions, both horizontally (authorities competent for related policy domains, e.g. nature conservation, cultural heritage) and vertically, at the national, regional and local levels.

3. <u>Task forces</u>

Organised groups of stakeholders can be defined as task forces to accompany the RAAs' designation process. One notable strength of this tool is the close engagement and familiarity each task force member gains with the planning process. This helps ensure more in-depth understanding of the planning procedure, thus facilitating the preparation of effective inputs. Task force members often represent very different stakeholder groups. Their continuous engagement in the task force can indeed foster coordination and collaboration and ensure a smooth integration of a broad spectrum of perspectives within the RAAs' planning process.

4. Expert consultations

Expert consultations involve seeking advice and insights from professionals with relevant expertise on RE technologies or environmental sensitivities. This could take the form of bilateral or group interviews and is generally an effective tool to gather specific knowledge and data to be integrated into the planning process, as well as to validate the process' conclusions.

5. Workshops

Workshops are a platform to bring stakeholders together to discuss, brainstorm and collaborate on specific topics that require the balance of different interests. In instances where a task force is not established, workshops can be instrumental in effectively structuring the stakeholder engagement and collecting the stakeholders' perspectives at pivotal stages of the RAAs planning process, such as to validate maps or develop shared solutions to emerging issues.

6. Open public consultations

Open consultations involve making planning information accessible to the public at an early stage, inviting input from a broad audience. They can be effectively employed by, for example, providing a window period after the publication of draft plans to gather feedback and to understand the perspectives of local residents and other stakeholders regarding the envisioned location of RAAs. This approach promotes transparency and community engagement, enabling the planning authority to address critical issues before they potentially escalate into legal disputes challenging the approved plans.

Box 5 – Best practice from Portugal

In creating maps to identify potential locations for RES development, Portugal's LNEG implemented an inclusive approach from the early stages of map development. It collaborated closely with authorities responsible for natural conservation, forestry, mining, and cultural heritage. The initial mapping of prospective areas for renewable electricity projects was released to the public in 2023, and feedback was actively sought. Additionally, a Task Force comprising of NGOs, electricity transmission and distribution operators, industry associations, and RES developers was established to accompany the entire planning process. Depending on the institutional structure, local entities such as the national association of municipalities may also be invited to participate, offering valuable feedback throughout the designation process.

Box 6 – Best practice from Croatia: Zadar County pilot project

EIHP, in partnership with TNC, conducted broad stakeholder consultations during the methodology development phase to obtain feedback on the proposed methodology as well as additional data that were not publicly available. On the basis of a stakeholder mapping exercise, EIHP identified a set of stakeholders to be invited for further collaboration, which included several categories:

- Officials from the relevant Ministries, such as the Ministry of Environment and Energy, the Ministry of Economy and Sustainable Development, the Ministry of Physical Planning, Construction and State Assets;
- Officials from the Zadar County relevant authorities - the Institute of Spatial Planning and the Department for Physical Planning, Environmental Protection and Public Utilities;
- Experts from academic institutions, e.g. experts on vulnerable habitats and species;
- Environmental NGOs.

The EIHP consultation strategy included (i) an introductory workshop to set up the collaboration, (ii) several bilateral interviews with specific focus on the methodology for the sensitivity assessment, followed by written feedback, (iii) a peer review workshop and (iv) an online survey, to validate the findings.

An open public consultation was also planned to engage the general public – primarily residents – but was finally not conducted due to limitations related to the COVID pandemic. Nevertheless, TNC and EIHP developed an online tool that allows the public to draw on a map the outlines of their preferred areas for solar and wind power plants development.

4. Environmental considerations to ensure low impacts

Harnessing energy from sources such as wind and solar can significantly decrease greenhouse gas emissions, air and water pollution, and habitat destruction associated with energy generation from fossil fuels. However, while renewable energy contributes to decarbonisation and climate change mitigation, these projects are, nevertheless, an infrastructure intervention. As such, they can have negative effects on ecosystems and wildlife. Understanding and addressing these impacts is crucial for ensuring the viability of renewable energy projects and the sustainability of the sector overall. Environmental impacts associated with onshore wind, offshore wind and solar PV energy technologies are elaborated in the following chapters. Box 7 explains the categories used for analysing impacts.

Organised by technology, the presentation of key environmental impacts in this chapter follows a structured format, with impacts summarised in tables, followed by detailed explanations. This approach aids readers in quickly accessing relevant information for their technology of interest, highlighting potential impacts for consideration during renewable energy project planning and development phases that are relevant for the designation of RAAs. The impacts presented in this chapter are not exhaustive but cover the most prominent and frequently identified types in the literature. Mitigation measures to address identified impacts are outlined in Chapter 5.

Box 7 – Categories used to analyse impacts

- **Type of Environmental Impact.** This category encompasses the grouping of similar impacts identified through literature review. It serves to categorise and classify the various impacts on the environment resulting from the project's activities, providing a comprehensive overview of its environmental footprint.
- **Effect.** This category provides a summary of the nature of the impact and how it manifests in the environment. It includes specific changes or consequences observed as a result of the project, although only at high level given the limitations of the tabular format.
- **Affected Ecosystem Element.** This category notes where the primary impact occurs, whether it is on species, habitats, or ecosystems. If it is possible to identify specific species / habitats / ecosystems, these are listed to an appropriate level.
- **Potential Magnitude of Impact.** This category qualitatively assesses the significance of the impact on the affected ecosystem element, ranging from low to high. For species, it evaluates the potential magnitude based on the sensitivity of the species to disturbance. For habitats, it considers resilience, habitat alteration, and fragmentation. For ecosystems, it examines the likelihood of impact based on ecosystem sensitivity and the extent of disruption to ecosystem processes or services. Assessment of magnitude reflects expert judgment based on information on impacts gathered from the literature, and it indicates ‘ worst-case scenario’ (i.e., the magnitude may be lower depending on actual conditions of the site and project details).
- **Spatial Extent of Impact.** This category delineates the reach of impacts beyond the project site. Impacts are categorised as immediate (confined within the project boundary), localised (affecting the project area and nearby surroundings, up to tens of kilometres), or extended (extending beyond the project and its nearby surroundings).
- **Life-cycle Stage.** This category notes the stage of the project cycle during which most of the impacts occur. It distinguishes between planning, construction, operation, and decommissioning, providing insights into when specific impacts are most prominent.

- **Technology-specific Cause.** This category identifies specific actions across all segments of the project that cause impacts. It includes activities related to the energy plant, grid connection, access to the location, or other project components, highlighting the underlying causes of environmental impacts.

4.1. Main environmental impacts of onshore wind projects

Onshore wind energy is a sustainable renewable energy source, but also produces some negative impacts on the environment in different life-cycle stages[31,32].The construction and decommissioning of onshore wind infrastructure require land clearance and may lead to the disturbance of habitats; the operation of wind turbines may result in collisions with, and disturbances to birds and bat species, and may also lead to noise and visual pollution. A summary of the main environmental impacts of onshore wind technology is provided in the table below, followed by a discussion of these impacts.

[31] Wiser, R., Z. Yang, M. Hand, O. Hohmeyer, D. Infi eld, P. H. Jensen, V. Nikolaev, M. O'Malley, G. Sinden, A. Zervos, 2011: Wind Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Retrieved from: https://www.ipcc.ch/site/assets/uploads/2018/03/Chapter-7-Wind-Energy-1.pdf p. 540.

[32] Bonou, A., Laurent, A., & Olsen, S.I. (2016). Life cycle assessment of onshore and offshore wind energy – from theory to application. (2016). Applied Energy, 180, 327-337. Available at: https://doi.org/10.1016/j.apenergy.2016.07.058.

Table 4-1 Summary of the main environmental impacts of onshore wind

Type of environmental impact	Effect	Affected ecosystem elements	Potential magnitude of impact	Spatial extent of impact	Life-cycle stage where impact is most likely	Technology-specific cause
● Collision	Birds and bats coming into contact with rotating wind turbine blades and overhead transmission lines, leading to injuries or fatalities	Birds: both resident and migratory, including raptors, migratory soaring birds, hornbills, hoopoes, storks, herons, shorebirds, gulls, eagles, vultures, buzzards, kites, falcons, swifts, kestrels, wild ducks Bats: migratory bats and foliage- and tree-roosting species (e.g. Vespertilionidae species), open-edge and edge-space foraging bats	Birds: low to high depending on species sensitivity and behaviour Bats: high due to potential attraction to turbines	Immediate to localised	Operation	Wind turbines; Overhead power lines
● Electrocution	Birds and bats getting electrocuted by power lines, leading to injuries or fatalities	Birds: small passerines, large soaring birds, large perching birds (e.g., eagles, hawks, vultures, kites, falcons, storks, corvids) Bats: large bat species (e.g. fruit bats)	Medium to high, depending on species susceptibility	Immediate to localised	Operation	Overhead power lines
● Barrier effect	Hindrance to movement for birds and terrestrial species due to closely-spaced wind turbines and associated infrastructure	Birds: soaring birds (including most raptors, storks, and other large birds), little tern, common tern, golden eagle, white-tailed eagle Mammals: European roe deer, European hare, red fox, wolves	Medium to high, depending on species and project scale	Localised to extended	Operation; Construction; Decommissioning	Wind turbines

Type of environmental impact	Effect	Affected ecosystem elements	Potential magnitude of impact	Spatial extent of impact	Life-cycle stage where impact is most likely	Technology-specific cause
● Habitat loss and displacement of species	Reduced animal presence in and around wind projects due to habitat loss or disturbance, affecting birds, bats, and terrestrial mammals	Birds: both resident and migratory species (e.g. red grouse, snipe and curlew) Bats that forage along forest edges Mammals: e.g., red fox, reindeer, European roe deer, European hare	High	Localised to Extended	Construction; Operation; Decommissioning	Wind turbines
● Noise	Noise disturbance affecting wildlife behaviour and health, potentially leading to stress, hearing loss, and habitat avoidance	Birds Bats Terrestrial mammals	Medium	Localised to extended	Construction; Operation; Decomissioning	Wind turbine
● Habitat degradation	Disturbance of land areas for wind turbine installation leading to a decline in habitat quality and introduction of invasive alien species	Natural habitats, directly and through changes in groundwater regime	Medium to high	Immediate to localised	Construction; Operation; Decommissioning	Wind turbine installation and associated infrastructure development

Legend: ● negative environmental impact

4.1.1. Collision

In the context of onshore wind projects and wildlife, collisions occur when birds or bats come into contact with the rotating blades of wind turbines. Birds and bats flying within the rotor swept area, i.e. the area which the turbine blade sweeps, are at risk of collisions that may result in injuries and/or death. This risk is present when wind turbines are in operation.

Factors affecting the collision risk for birds and bats are **specific to the site, species and turbine design**[33]**.** The size and alignment of wind turbines and rotor speed, as well as warning lights, are other possible factors that could influence birds' collision risk[34]. The risk of collision is influenced by factors such as the likelihood of birds flying at the height of wind turbines and power lines, as well as their ability to detect these structures in time to avoid collision. Species-specific behaviours play a significant role, with aerial species facing higher exposure but potentially mitigating risk by flying above structures, while larger terrestrial species may have lower exposure but higher effective risk due to their typical flying height aligning with these structures. Additionally, susceptibility to collision is influenced by physical traits such as size, weight, and wing structure.

Bird species vulnerable to collision with onshore wind infrastructure include raptors, migratory soaring birds, Bucerotiformes (hornbills and hoopoes), Ciconiformes (storks and herons), and some Charadriiformes (shorebirds)[35].

Species at risk also include the Lesser black-backed gull (*Larus fuscus*), Common gull (*Larus canus*), European herring gull (*Larus argentatus*), Golden eagle (*Aquila chrysaetos*), and White-tailed eagle (*Haliaeetus albicilla*)[36]. Collisions involving these eagles emphasise the importance of avoiding development near their breeding areas and migration routes[37].

An ongoing study on bird and bat sensitivity around wind turbines[38] identifies additional vulnerable species such as the Eurasian griffon vulture (*Gyps fulvus*), Common buzzard (*Buteo buteo*), Red kite (*Milvus milvus*), and Black-headed gull (*Larus ridibundus*), as well as passerines such as the Eurasian skylark (*Alauda arvensis*), Corn bunting (*Emberiza calandra*), common swift (*Apus apus*), common Kestrel (*Falco tinnunculus*), and wild duck (*Anas platyrhynchos*).

Large terrestrial and wetland birds, along with smaller, fast-flying species, are generally prone to collisions with wind turbines[39] and overhead power lines[40]. A study carried out in 2020 by

[33] Laranjeiro, T., May, R., & Verones, F. (2018). Impacts of onshore wind energy production on birds and bats: recommendations for future life cycle impact assessment developments. The International Journal of Life Cycle Assessment, 23, 2007-2023. Doi: 10.1007/s11367-017-1434-4.
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[35] Thaxter, C. B., Buchanan, G. M., Carr, J., Butchart, S. H., Newbold, T., Green, R. E., & Pearce-Higgins, J. W. (2017). Bird and bat species' global vulnerability to collision mortality at wind farms revealed through a trait-based assessment. Proceedings of the Royal Society B: Biological Sciences, 284(1862), 20170829. https://doi.org/10.1098/rspb.2017.0829.
[36] Balotari-Chiebao, F., Valkama, J., & Byholm, P. (2021). Assessing the vulnerability of breeding bird populations to onshore wind-energy developments in Finland. Ornis Fennica. Retrieved from: https://tethys.pnnl.gov/sites/default/files/publications/Balotari-Chiebao-et-al-2021.pdf.
[37] Ibidem.
[38] Ongoing study within Technical and scientific support in relation to the Habitats and Birds Directives (Contract N°09.0201/2021/855807/SER/ENV.D.3) commissioned by DG ENV of the European Commission on Windmills sensitive species in EU 27.
[39] Ibidem.
[40] Jenkins, A. R., Smallie, J. J., & Diamond, M. (2010). Avian collisions with power lines: a global review of causes and mitigation with a South African perspective. Bird Conservation International, 20(3), 263-278. https://doi.org/10.1017/S0959270910000122.

Wageningen University & Research[41] shows that excess mortality[42] due to collisions can significantly impact bird populations. Species with longer generations, low reproductive rates, or high habitat specialisation are particularly vulnerable[43]. However, impacts on local populations vary among species, with some exhibiting limited differences in trends between operational wind farms and reference sites[44].

Bird behaviour around turbines is complex and may include avoidance strategies, though their effectiveness varies. Studies have shown that birds are capable of avoiding turbine blades by flying around or over the turbines[45], although this behaviour varies between species and across different spatial and temporal dimensions[46,47]. Migratory birds are particularly vulnerable, especially near breeding sites or migration pathways. For instance, white storks (*Ciconia ciconia*) face higher collision risks due to their reliance on updrafts and habitats favoured for wind energy development, coupled with their attraction to adjacent agricultural land for foraging[48].

Bats also face a collision risk. Studies have shown that bats seem to be undisturbed by wind turbines, and in some cases, may be attracted to them, increasing the number of collisions[49]. The attraction for insect-eating bats, such as the Vespertilionidae species[50] could be caused by large number of insects which may be drawn to wind turbines or the landscape features created by wind project development; tree-roosting bats may also be attracted to wind turbines as they consider the structure as potential roosts[51]. This implies that the risk is mainly present in the operational phase, where insects may be attracted to the turbines. Forest clearance for wind turbine construction and operation also increases bat activity, in particular, for open-space and edge-space foraging bats[52]. Mortality for bats was noted to be highest during low wind speeds and increased wind turbine tower height and rotor diameter[53].

4.1.2. Electrocution

Birds and bats face the risk of electrocution by power transmission and distribution lines, which may result in injuries and mortality. The risk of electrocution is greatest on medium voltage power lines, which may be used by birds for perching, roosting and even nesting. Avian deaths

[41] Wageningen University & Research. (2020). Effect of wind turbines on bird mortality often underestimated. Retrieved from: https://www.wur.nl/en/research-results/research-institutes/environmental-research/show-wenr/effect-of-wind-turbines-on-bird-mortality-often-underestimated.htm.
[42] Excess mortality occurs when the observed number of deaths over a particular period is higher than the number expected for the same period.
[43] Balotari-Chiebao, F., Valkama, J., & Byholm, P. (2021). Assessing the vulnerability of breeding bird populations to onshore wind-energy developments in Finland. Ornis Fennica. Retrieved from: https://tethys.pnnl.gov/sites/default/files/publications/Balotari-Chiebao-et-al-2021.pdf.
[44] Pearce-Higgins, J. W., Stephen, L., Douse, A., & Langston, R. H. (2012). Greater impacts of wind farms on bird populations during construction than subsequent operation: results of a multi-site and multi-species analysis. Journal of Applied Ecology, 49(2), 386-394. https://doi.org/10.1111/j.1365-2664.2012.02110.x.
[45] Vattenfall. (2020). Birds are good at avoiding wind turbine blades. Retrieved from: https://group.vattenfall.com/press-and-media/newsroom/2020/birds-are-good-at-avoiding-wind-turbine-blades.
[46] Santos, C. D., Ramesh, H., Ferraz, R., Franco, A. M., & Wikelski, M. (2022). Factors influencing wind turbine avoidance behaviour of a migrating soaring bird. Scientific Reports, 12(1), 6441. https://doi.org/10.1038/s41598-022-10295-9.
[47] Max Planck Society. (2022). Can wind turbines and migrating birds coexist? Retrieved from: https://phys.org/news/2022-04-turbines-migrating-birds-coexist.html.
[48] WREN Short Science Summary. (n.d.). White Storks in Europe Onshore Wind Energy. Retrieved from: https://tethys.pnnl.gov/sites/default/files/summaries/WREN-Short-Science-Summary-White-Stork.pdf.
[49] Foo, C. F., Bennett, V. J., Hale, A. M., Korstian, J. M., Schildt, A. J., & Williams, D. A. (2017). Increasing evidence that bats actively forage at wind turbines. *PeerJ*, *5*, e3985. https://doi.org/10.7717/peerj.3985.
[50] Thaxter, C. B., Buchanan, G. M., Carr, J., Butchart, S. H., Newbold, T., Green, R. E., & Pearce-Higgins, J. W. (2017). Bird and bat species' global vulnerability to collision mortality at wind farms revealed through a trait-based assessment. Proceedings of the Royal Society B: Biological Sciences, 284(1862), 20170829. https://doi.org/10.1098/rspb.2017.0829.
[51] Lloyd, J. D., Butryn, R., Pearman-Gillman, S., & Allison, T. D. (2023). Seasonal patterns of bird and bat collision fatalities at wind turbines. Plos one, 18(5), e0284778. https://doi.org/10.1371/journal.pone.0284778.
[52] Ellerbrok, J. S., Farwig, N., Peter, F., Rehling, F., & Voigt, C. C. (2023). Forest gaps around wind turbines attract bat species with high collision risk. Biological Conservation, 288, 110347. https://doi.org/10.1016/j.biocon.2023.110347.
[53] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Pg 63. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.

can occur either by short-circuits, earthed-faults, or by falling from a height after being electrocuted[54]. According to BirdLife, diurnal bird species, specifically eagles, hawks, vultures, kites, falcons, storks and corvids experience high mortality rate due to this. The negative impact on a specific species can occur at the local scale, and also at the population level[55]. The **frequency of bird mortality from electrocution may also vary per season**, for example in early Spring (March) and late summer (September, when there are high numbers of juvenile birds, and according to other factors such as migratory activity, bird population densities, etc.).

4.1.3. Barrier effect

The physical and/or psychological hindrance to movement, for both birds and terrestrial species, as a result of closely-spaced wind turbines, and the development of new roads and transmission lines, is known as the barrier effect[56]. Animals have to spend additional energy to avoid wind turbines and associated infrastructure[57], which can alter foraging patterns and breeding behaviour, leading to negative impacts on breeding success and population density for birds and terrestrial species. The barrier effect is present during the operational stage of a project, as well as during its construction and decommissioning. Cumulative effects may occur when animals must navigate multiple wind farms, particularly affecting migratory birds, and leading to potential fatigue and displacement[58].

Studies have shown that soaring birds, including most raptors, storks and other large birds, alter their flight paths to avoid wind turbines, which may lead to their displacement[59,60].

Species like the little tern (*Sternula albifrons*) and the common tern (*Sterna hirundo*) can be significantly affected by turbines near breeding colonies or flight paths, while collisions among the Golden eagle (*Aquila chrysaetos*) and White-tailed eagle (*Haliaeetus albicilla*) highlight the need to move large-scale development works away from important breeding areas, habitats and migration routes of these migratory species[61].

In a study on the White-tailed eagle (*Haliaeetus albicilla*) in western Norway, land within 500 m of wind turbines was found to experience significantly lower breeding success than pre-construction. However, the barrier effect is reduced significantly when an avoidance buffer of 1 km is present, potentially mitigating environmental impact[62]. Construction and

[54] BirdLife International. (2022). Electrocutions & Collisions of Birds in EU Countries. Page 14. Retrieved from: https://www.birdlife.org/wp-content/uploads/2022/10/Electrocutions-Collisions-Birds-Best-Mitigation-Practices-NABU.pdf.
[55] Ibidem.
[56] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[57] Laranjeiro, T., May, R., & Verones, F. (2018). Impacts of onshore wind energy production on birds and bats: recommendations for future life cycle impact assessment developments. The International Journal of Life Cycle Assessment, 23, 2007-2023. Doi: 10.1007/s11367-017-1434-4.
[58] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[59] Marques, A. T., Batalha, H., & Bernardino, J. (2021). Bird Displacement by Wind Turbines: Assessing Current Knowledge and Recommendations for Future Studies. Birds, 2(4), 460-475. https://doi.org/10.3390/birds2040034.
[60] Marques, A. T., Santos, C. D., Hanssen, F., Muñoz, A. R., Onrubia, A., Wikelski, M., ... & Silva, J. P. (2020). Wind turbines cause functional habitat loss for migratory soaring birds. Journal of Animal Ecology, 89(1), 93-103. https://doi.org/10.1111/1365-2656.12961.
[61] Balotari-Chiebao, F., Valkama, J., & Byholm, P. (2021). Assessing the vulnerability of breeding bird populations to onshore wind-energy developments in Finland. Ornis Fennica. Retrieved from: https://tethys.pnnl.gov/sites/default/files/publications/Balotari-Chiebao-et-al-2021.pdf.
[62] Dahl, E. L., Bevanger, K., Nygård, T., Røskaft, E., & Stokke, B. G. (2012). Reduced breeding success in white-tailed eagles at Smøla windfarm, western Norway, is caused by mortality and displacement. Biological Conservation, 145(1), 79-85. https://doi.org/10.1016/j.biocon.2011.10.012.

decommissioning works can also cause disturbance during the breeding and / or migration periods of birds and other animals[63].

Additionally, terrestrial species like European roe deer (*Capreolus capreolus*), European hare (*Lepus europaeus*), red fox (*Vulpes vulpes*), and wolves exhibit avoidance behaviours, leading to habitat displacement due to an effective loss of habitat. This can also lead to shifts in trophic cascades, where changes in predator-prey dynamics due to removal (or addition of top predator) may impact populations lower in the food chain, thus altering ecosystems[64].

4.1.4. Habitat loss and displacement of species

Displacement, characterised by reduced animal presence in and around wind projects due to habitat loss or disturbance, affects birds, bats, and terrestrial mammals across all stages of wind power projects. Functional loss of habitat is exhibited as reduction of habitat quality and habitat availability[65,66], altering behaviour of species towards finding new nesting, breeding, foraging/hunting, and migration areas. Displacement due to functional habitat loss is among the most significant impacts of onshore wind power on populations of certain bird species[67,68].

Displacement effects have been observed within 200 m to over 800 m from turbines[69]. An analysis of 286 trials reported in 71 peer-reviewed studies shows that displacement effects were reported for the majority of the trials involving Gaviiformes (100%), Anseriformes (68.2%), Suliformes (66.7%), Accipitriformes (48.7%) and Falconiformes (50.0%)(Figure 4-1). The spatial extent of the displacement effect of these species varies across different taxonomies and studies where the reported mean distances (± standard deviation) are: Gaviiformes 12 062 m (± 6911 m); Anseriformes 116 m (± 64 m); Accipitriformes 474 m (± 213 m); data for Suliformes and Falconiformes was insufficient[70].

A study conducted in Finland revealed that birds such as geese, ducks, and waders, also tend to experience reduced bird density due to displacement; notable examples of species affected are Common pochard (*Aythya farina*), Greater scaup (*Aythya marila*), Bean goose (*Anser fabalis*) and Black-tailed godwit (*Limosa limosa*), Eurasian goshawk (*Accipiter gentilis*), Common buzzard (*Buteo buteo*), and Willow tit (*Poecile montanus*)[71].

However, other studies report different results for some of these species; for example, a systematic review of 84 peer-reviewed studies of onshore wind power identified no

[63] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[64] Ibidem.
[65] Laranjeiro, T., May, R., & Verones, F. (2018). Impacts of onshore wind energy production on birds and bats: recommendations for future life cycle impact assessment developments. The International Journal of Life Cycle Assessment, 23, 2007-2023. Doi: 10.1007/s11367-017-1434-4.
[66] Dahl, E. L., Bevanger, K., Nygård, T., Røskaft, E., & Stokke, B. G. (2012). Reduced breeding success in white-tailed eagles at Smøla windfarm, western Norway, is caused by mortality and displacement. Biological Conservation, 145(1), 79-85. https://doi.org/10.1016/j.biocon.2011.10.012.
[67] Laranjeiro, T., May, R., & Verones, F. (2018). Impacts of onshore wind energy production on birds and bats: recommendations for future life cycle impact assessment developments. The International Journal of Life Cycle Assessment, 23, 2007-2023. Doi: 10.1007/s11367-017-1434-4.
[68] Marques, A. T., Santos, C. D., Hanssen, F., Muñoz, A. R., Onrubia, A., Wikelski, M., ... & Silva, J. P. (2020). Wind turbines cause functional habitat loss for migratory soaring birds. Journal of Animal Ecology, 89(1), 93-103. https://doi.org/10.1111/1365-2656.12961.
[69] European Commission, Directorate-General for Environment. (2020). Guidance document on wind energy developments and EU nature legislation. Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2779/457035.
[70] Marques, A. T., Batalha, H., & Bernardino, J. (2021). Bird Displacement by Wind Turbines: Assessing Current Knowledge and Recommendations for Future Studies. Birds, 2(4), 460-475. https://doi.org/10.3390/birds2040034.
[71] Balotari-Chiebao, F., Valkama, J., & Byholm, P. (2021). Assessing the vulnerability of breeding bird populations to onshore wind-energy developments in Finland. Ornis Fennica. Retrieved from: https://tethys.pnnl.gov/sites/default/files/publications/Balotari-Chiebao-et-al-2021.pdf.

displacement impacts on waders[72]. This highlights the importance of considering specific site conditions and local wildlife to understand the scale of impact.

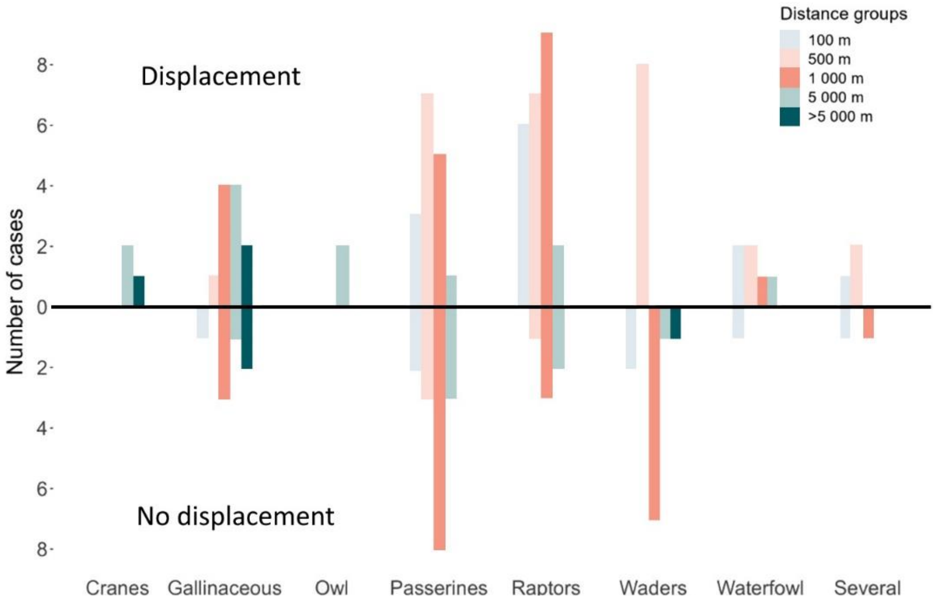

Figure 0-3 Bird functional groups classified in five distance categories and differentiated by whether displacement was observed[73]

A study carried out in the United Kingdom, which considered the impacts on 10 different bird species at five or more wind projects in the construction and post-construction phase over 3 years, showed that the extent and severity of disturbance and consequent displacement is dependent on the characteristics of the site and species[74]. The study also concluded that the **displacement impact on bird populations was higher in the construction phase** than in the operational phase. During the construction phase, the population densities of the red grouse, snipe and curlew were reduced, although the red grouse densities appeared to recover within a year. On the other hand, the population density of curlew seemed to recover poorly, and may have declined by about 40%; earlier studies had also identified a 30% decrease in bird population density within a 1-km radius of wind turbines[75].

For bats, displacement may occur due to an increase in human activities in and around roost sites such as habitat removal or the activities of maintenance vehicles and personnel, which may result in changes in temperature, humidity, light, noise and vibration, resulting in a reduction in use of habitats as roosting or reproductive sites. It could also result in a shift of flight corridors, or deter bats from foraging habitats that they would otherwise use[76]. Other studies also recorded displacement of bats (21 out of 29 cases), with a reported median displacement distance of 1 km (which was also the maximum distance that was surveyed)[77]. However, none of these studies included observations before the development of wind

[72] Stewart, G. B., Pullin, A. S., & Coles, C. F. (2007). Poor evidence-base for assessment of windfarm impacts on birds. Environmental Conservation, 34(1), 1-11. doi:10.1017/S0376892907003554.
[73] Tolvanen, A., Routavaara, H., Jokikokko, M., & Rana, P. (2023). How far are birds, bats, and terrestrial mammals displaced from onshore wind power development?–A systematic review. Biological Conservation, 288, 110382. http://dx.doi.org/10.1016/j.biocon.2023.110382.
[74] Pearce-Higgins, J. W., Stephen, L., Douse, A., & Langston, R. H. (2012). Greater impacts of wind farms on bird populations during construction than subsequent operation: results of a multi-site and multi-species analysis. Journal of Applied Ecology, 49(2), 386-394. https://doi.org/10.1111/j.1365-2664.2012.02110.x.
[75] Ibidem.
[76] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/457035.
[77] Tolvanen, A., Routavaara, H., Jokikokko, M., & Rana, P. (2023). How far are birds, bats, and terrestrial mammals displaced from onshore wind power development?–A systematic review. Biological Conservation, 288, 110382. http://dx.doi.org/10.1016/j.biocon.2023.110382.

turbines. The reactions of bats to changes in their habitat were significantly influenced by both the type of their foraging habitat (forest, boundary, open areas) and the echolocation capabilities of the species (short, medium, long range). Forest species such as *Myotis sp*., the Western barbastelle (*Barbastella barbastellus*), appears to be more vulnerable to displacement due to loss in habitat quality (because of forest clearance, noise, and red aviation lights) and loss in foraging habitat. A recent study also found that the activity of narrow-space foraging bats decreases by 77% on average within a radius of 80 m to 450 m around operating wind turbines, as the wind speeds increase[78]. On the other hand, the clearance of forests may benefit bat species that prefer foraging along forest edges and gaps[79,80].

An international review of 84 peer-reviewed studies of onshore wind identified several studies that recorded displacement of terrestrial mammals. Displacement of terrestrial mammals is usually due to changes in the area usage, decrease in habitat quality (for example, due to noise), habitat loss and fragmentation, which can result in reduced grazing areas. A summary of the studies that were relevant to species found in Europe is provided below[81].

Table 4-2 Summary of studies that recorded displacement of terrestrial mammals in Europe

Family	Species	Study	Observation	No. of studies	Country of study
Canidae	Red fox *(Vulpes vulpes)*	• Łopucki, R., Klich, D. & Gielarek, S. (2017). Do terrestrial animals avoid areas close to turbines in functioning wind farms in agricultural landscapes?. Environ Monit Assess 189, 343. https://doi.org/10.1007/s10661-017-6018-z	• Displacement up to 700 m	1	Poland
Vervidae	Reindeer *(Rangifer tarandus)*	• Skarin, A., Alam, M. (2017). Reindeer habitat use in relation to two small wind farms, during preconstruction, construction, and operation. Ecol. Evol. 7, 3870–3882. https://doi.org/10.1002/ece3.2941 • Skarin, A., Nellemann, C., R¨ onnegård, L., Sandstr¨ om, P., Lundqvist, H. (2015). Wind farm construction impacts reindeer migration and movement corridors. Landsc. Ecol. 30, 1527–1540 • Skarin, A., Sandstr¨om, P., Alam, M. (2018). Out of sight of wind turbines-reindeer response to wind farms in operation. Ecol. Evol. 8, 9906–9919. https://doi.org/10.1002/ece3.4476 • Colman, J.E., Eftestøl, S., Tsegaye, D., Flydal, K., Mysterud, A. (2013). Summer distribution of semi-domesticated reindeer relative to a new wind-power plant. Eur. J. Wildl. Res. 59, 359–370. https://doi.org/10.1007/s10344-012-0682-7 • Tsegaye, D., Colman, J.E., Eftestøl, S., Flydal, K., Røthe, G., Rapp, K. (2017). Reindeer spatial use before, during and after construction of a wind farm. Appl. Anim.	• Displacement recorded in all studies • Displacement from 100 m to the access road and up to 15 km from wind turbine • Displacement due to decline in habitat quality; • Displacement occurred especially during construction phase, and during operation phase;	6	Sweden – same area but on different occasions

[78] Leibniz Institute for Zoo and Wildlife Research (Leibniz-IZW). (4 Jan 2024). Conflict in full swing: Forest bats avoid large areas around fast-moving wind turbines. Accessed at: https://www.izw-berlin.de/en/press-release/conflict-in-full-swing-forest-bats-avoid-large-areas-around-fast-moving-wind-turbines.html.
[79] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[80] Ellerbrok, J.S., Delius, A., Peter, F., Farwig, Voigt C.C., 2022. Activity of forest specialist bats decreases towards wind turbines at forest sites. J. Appl. Ecol. 9, 2497–2506. https://doi.org/10.1111/1365-2664.14249.
[81] Tolvanen, A., Routavaara, H., Jokikokko, M., & Rana, P. (2023). How far are birds, bats, and terrestrial mammals displaced from onshore wind power development?–A systematic review. Biological Conservation, 288, 110382. http://dx.doi.org/10.1016/j.biocon.2023.110382.

Family	Species	Study	Observation	No. of studies	Country of study
		Behav. Sci. 195, 103–111. https://doi.org/10.1016/j.applanim.2017.05.023. • Eftestøl, S., Tsegaye, D., Flydal, K., Colman, J.E. (2023). Effects of wind power development on reindeer: global positioning system monitoring and Herders' experience. Rangel. Ecol. Manag. 87, 55–68. https://doi.org/10.1016/j.rama.2022.11.011	• More sensitive during calving season due to noise		
	European roe deer *(Capreolus capreolus)*	• Łopucki, R., Klich, D. & Gielarek, S. (2017). Do terrestrial animals avoid areas close to turbines in functioning wind farms in agricultural landscapes?. Environ Monit Assess 189, 343. https://doi.org/10.1007/s10661-017-6018-z	• Displacement up to 600 – 700 m • Displacement potentially due to noise – difficult to hear and to sense predators	1	
Small mammals	European hare *(Lepus europaeus)*	• Łopucki, R., Klich, D. & Gielarek, S. (2017). Do terrestrial animals avoid areas close to turbines in functioning wind farms in agricultural landscapes?. Environ Monit Assess 189, 343. https://doi.org/10.1007/s10661-017-6018-z	• Displacement up to 700 m	1	
	Small rodents, shrews, hedgehogs and hamsters	• de Lucas, M., Janss, G.F.E., Ferrer, M. (2005). A bird and small mammal BACI and IG design studies in a wind farm in Malpica (Spain). Biodivers. Conserv. 14, 3289–3303. https://doi.org/10.1007/s10531-004-0447-z • Łopucki, R., Mróz, I. (2016). An assessment of non-volant terrestrial vertebrates response to wind farms—a study of small mammals. Environ. Monit. Assess. 188, 122. https://doi.org/10.1007/s10661-016-5095-8 • Łopucki, R., Perzanowski, K. (2018). Effects of wind turbines on spatial distribution of the European hamster. Ecol. Indic. 84, 433–436. https://doi.org/10.1016/j. ecolind.2017.09.019	• No displacement	3	Poland, Spain

A study on the impacts of wind power on terrestrial mammals found that in the construction and decommissioning phases, disturbances to terrestrial mammals arising from increased human activity and traffic, land clearance, and other activities may affect animal behaviour and spatial distribution[82]. Studies have shown that some terrestrial mammals may display temporary avoidance of wind turbines, especially during the construction phase, although the data is inconclusive. Nonetheless, should the period of construction works last too long, prolonged disturbance could also lead to a permanent displacement for certain species.

In the operation phase, large carnivores and ungulates including the domestic reindeer, moose, and other larger wildlife, may experience a loss of habitat which could be attributed to the network of access roads to the turbines, increasing access for recreation, hunting, and leisure traffic. If new wind projects are located in upland, remote areas mainly in the forested

[82] Helldin, J. O., Jung, J., Neumann, W., Olsson, M., Skarin, A., & Widemo, F. (2012). The impacts of wind power on terrestrial mammals: a synthesis. Naturvårdsverket. Available at: https://www.naturvardsverket.se/globalassets/media/publikationer-pdf/ovriga-pub/vindval/978-91-620-6510-2.pdf.

landscape, it may disturb refuge areas for large predators and grazing areas for ungulates, which may result in a population decline of these species.

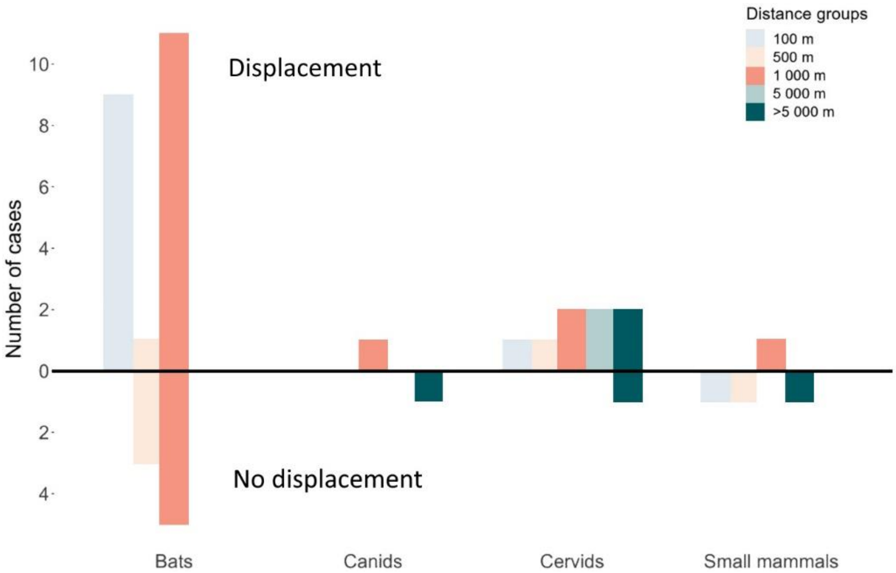

Figure 0-4 Bats and terrestrial mammals classified in five distance categories and differentiated by whether displacement was observed[83]

4.1.5. Noise

Studies have shown that onshore wind results in noise pollution when in operation. Noise produced by wind turbines can be categorised into two types: mechanical noise that comes from the gearboxes and generators, and the aerodynamic noise from the turbine blades, with the latter being the key discussion point concerning the sound produced by onshore wind turbines[84].

Wind turbine noise can impact birds negatively as it may disrupt mechanisms that are needed for their survival. Noise can lead to increased stress levels or even hearing loss (physiological damage). It may also trigger an increase in anti-predatory behaviours and extra alertness, which may cost them extra energy that could otherwise be used for foraging for food. It might also impede the transmission of communication signals to their intended recipients, diminishing the amount of information extractable from a signal, including vital sounds signalling the presence of an approaching predator or prey[85]. Despite the lack of studies regarding the impacts of noise on wildlife, there is some correlation between noise and species demography (community composition, population density etc.) and habitat avoidance (mainly in bird species, but also mammals)[86]. Noise generated by wind turbines has shown to affect

[83] Tolvanen, A., Routavaara, H., Jokikokko, M., & Rana, P. (2023). How far are birds, bats, and terrestrial mammals displaced from onshore wind power development?–A systematic review. Biological Conservation, 288, 110382. http://dx.doi.org/10.1016/j.biocon.2023.110382.
[84] Wind Energy The Facts. (n.d.). Noise impact. Retrieved from: https://www.wind-energy-the-facts.org/onshore-impacts-5.html.
[85] Teff-Seker, Y., Berger-Tal, O., Lehnardt, Y., & Teschner, N. (2022). Noise pollution from wind turbines and its effects on wildlife: A cross-national analysis of current policies and planning regulations. Renewable and Sustainable Energy Reviews, 168, 112801. https://doi.org/10.1016/j.rser.2022.112801.
[86] Teff-Seker, Y., Berger-Tal, O., Lehnardt, Y., & Teschner, N. (2022). Noise pollution from wind turbines and its effects on wildlife: A cross-national analysis of current policies and planning regulations. Renewable and Sustainable Energy Reviews, 168, 112801. https://doi.org/10.1016/j.rser.2022.112801.

the mating success rate of birds during lekking (mating) seasons, as they affect the vocalisations of lekking greater prairie-chicken males (*Tetrao urogallus*)[87].

Echolocation calls of bats provide reliable sensory perception for navigation and foraging at night[88]. However, noise and vibration could potentially distract foraging bats[89]. Some researchers hypothesise that noise emitted from rotating wind turbines, generators or other electronics, could be misinterpreted by bats as prey and attract them to the wind turbines; however, this hypothesis still has to be proven[90]. Noise from wind turbines also affects terrestrial mammals as it disrupts animal vocal communication and may also impair their ability to sense predators and to hunt. In addition, noise may also lead to increased stress levels. Stress levels have been found to be higher in badgers (*Meles meles*) living less than 1 km from a wind project as compared to badgers living more than 10 km away from a wind project. Noise may also increase stress levels for domestic animals which are fenced and have limited opportunities for movement[91].

4.1.6. Habitat degradation

Infrastructure development works in general entail the disturbance of land areas, which can lead to a decline in the quality of natural habitats. For onshore wind projects, infrastructure development includes the wind turbines, grid connection infrastructure, i.e. transmission and distribution lines, co-located storage facilities and access roads. The impacts on the quality of habitats could vary significantly depending on the previous land-use, e.g. higher impact when pristine areas are being cleared versus a lower impact when degraded land is used. However, the physical footprint of onshore wind projects is usually relatively small[92]. Onshore wind turbines are tall, vertical structures which occupy minimal land area, and can coexist with other land uses such as agriculture and grazing.

Generally, infrastructure development works also introduce a risk of invasive alien species which can threaten the native ecosystem. This may occur, for example, through the transport of soil on machinery and work tools. The clearance of land may also facilitate the spread of invasive alien species in these open spaces[93].

The construction of a wind project may also impact groundwater quantity and flow regime, possibly leading to wider ecosystem impacts, such as reduced water availability, changes in ecology or land stability[94]. An overview of the potential impacts on groundwater from wind power projects is summarised in the table below.

[87] Taubmann, J., Kämmerle, J. L., Andrén, H., Braunisch, V., Storch, I., Fiedler, W., ... & Coppes, J. (2021). Wind energy facilities affect resource selection of capercaillie Tetrao urogallus. Wildlife biology, 2021(1), 1-13. https://doi.org/10.2981/wlb.00737. The study investigated the effect of wind turbines located 865 m away from the greater prairie-chickens' habitat.
[88] Guest, E. E., Stamps, B. F., Durish, N. D., Hale, A. M., Hein, C. D., Morton, B. P., ... & Fritts, S. R. (2022). An updated review of hypotheses regarding bat attraction to wind turbines. Animals, 12(3), 343. https://doi.org/10.3390%2Fani12030343.
[89] Allen, L. C., Hristov, N. I., Rubin, J. J., Lightsey, J. T., & Barber, J. R. (2021). Noise distracts foraging bats. Proceedings of the Royal Society B, 288(1944), 20202689. https://doi.org/10.1098/rspb.2020.2689.
[90] Guest, E. E., Stamps, B. F., Durish, N. D., Hale, A. M., Hein, C. D., Morton, B. P., ... & Fritts, S. R. (2022). An updated review of hypotheses regarding bat attraction to wind turbines. Animals, 12(3), 343. https://doi.org/10.3390/ani12030343.
[91] Helldin, J. O., Jung, J., Neumann, W., Olsson, M., Skarin, A., & Widemo, F. (2012). The impacts of wind power on terrestrial mammals: a synthesis. Naturvårdsverket. Retrieved from: https://www.naturvardsverket.se/globalassets/media/publikationer-pdf/ovriga-pub/vindval/978-91-620-6510-2.pdf.
[92] Hamed, T. A., & Alshare, A. (2022). Environmental impact of solar and wind energy-a review. Journal of Sustainable Development of Energy, Water and Environment Systems, 10(2), 1-23. DOI: https://doi.org/10.13044/j.sdewes.d9.0387.
[93] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[94] Department of the Environment and Northern Ireland Environment Agency. (2015). Wind farms and groundwater impacts: A guide to EIA and Planning considerations, version 1.1. Retrieved from: https://niopa.qub.ac.uk/bitstream/NIOPA/7351/1/Wind%20farms%20and%20groundwater%20impacts.pdf.

Table 4-3 Potential impacts on groundwater from wind projects[95]

	Construction phase	Operational phase	Decommissioning phase
Groundwater flow regime	**Earthworks and site drainage:** • Reduction in water table if dewatering is required for turbine foundation construction or borrow pits; • Changes to groundwater distribution and flow.	**Physical presence of turbines and tracks:** • Possible changes to groundwater distribution; • Reduction in groundwater storage. **Reduction of forestry in site area:** • Changes to infiltration and surface runoff patterns, thereby influencing groundwater flow and distribution.	**Physical presence of former turbines and tracks:** • Possible changes to groundwater distribution; • Reduction in groundwater storage.
Groundwater quality	**Earthworks:** • Disturbance of contaminated soil and subsequent groundwater pollution. **Materials Management:** • Pollution from spills or leaks of fuel, oil and building materials.	**Materials Management:** • Pollution from spills or leaks of fuel or oil.	**Use of vehicles and machinery to remove infrastructure:** • Pollution from spills or leaks of fuel or oil.

4.1.7. Other potential environmental impacts

Barotrauma. Barotrauma results from damages to body tissues due to the exposure to pressure variations caused by rotating turbine blades, which can lead to injury of death. A study carried out in 2008 by Baerwald et al. presented evidence that bats were killed more often by barotrauma around wind turbines, rather than impact trauma. However, this conclusion is not definitive, as another study carried out in 2020 found contradictory results, suggesting that barotrauma may not be the main cause for bat mortality[96].

Exploitation. The creation of access roads into previously remote areas may lead to natural resource extraction or exploitation of vulnerable species, i.e. increase in poaching activity[97].

Changes to local climate and ecosystem. Some studies suggest that wind turbines may affect local climate and ecosystems through drying of soils in grassland areas, especially as wind turbines become larger in size and are more widespread[98].

Pollution during infrastructure works. The construction, decommissioning and repowering of onshore wind projects can result in light, solid and liquid waste and dust being produced;

[95] Ibidem, page 4.
[96] Lawson, M., Jenne, D., Thresher, R., Houck, D., Wimsatt, J., & Straw, B. (2020). An investigation into the potential for wind turbines to cause barotrauma in bats. Plos one, 15(12), e0242485. https://doi.org/10.1371/journal.pone.0242485.
[97] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Pg 65. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[98] See for example, Chapman, J. (2018). Climatic and human impact on the environment?: A question of scale. Quaternary International, 496, 3-13. https://doi.org/10.1016/j.quaint.2017.08.010; Miller, L. M., & Keith, D. W. (2018). Climatic impacts of wind power. Joule, 2(12), 2618-2632. https://doi.org/10.1016/j.joule.2018.09.009; and Wang, G., Li, G., & Liu, Z. (2023). Wind farms dry surface soil in temporal and spatial variation. Science of The Total Environment, 857, 159293. https://doi.org/10.1016/j.scitotenv.2022.159293.

however, these are consistent with infrastructure development works in general, and are not specific to onshore wind projects[99].

4.2. Main environmental impacts of offshore wind energy projects

The majority of scientific literature analysed for the purpose of this project concurs on the main environmental impacts associated with the development of offshore wind energy projects. The impacts concern the underwater noise, different types of pollution, collision of animals with the turbines and vessels, emission of electromagnetic fields from the connection cables, habitat loss and degradation, and barrier effects. There is also scientific evidence that offshore wind projects may support the creation of artificial reefs, and therefore possibly affect certain ecosystem elements of the marine environment in a positive way. While there is a consensus that further research is required to fully understand the key impacts and their interactions, the impacts presented here should be carefully considered during the planning and development of RAAs for offshore wind projects.

A summary of the main environmental impacts of offshore wind technology is provided in the table below, followed by an elaboration of these impacts.

[99] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Pg 45. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.

Table 4-4 Summary of main offshore wind environmental impacts

Environmental impact	Effect	Affected ecosystem elements	Potential magnitude of impact	Spatial extent of impact	Life-cycle stage where impact is most likely	Technology-specific cause
● Noise	Underwater noise is created due to wind farm-related activities in all life- cycle stages (e.g., pile driving detonations, mechanics of the turbines) that disturbs the hearing and the communication of marine animals	Marine mammals: dolphins, porpoises, cetaceans Fish: salmon, shad species, lamprey	High for sensitive species such as dolphins, porpoises, and cetaceans, especially during construction. Medium to high, particularly for coastal or estuarine waters, where fish with swim bladders are more sensitive	Immediate to localised, affecting species and habitats within the vicinity of the project site	Construction; Operation	Pile driving; Detonations; Geophysical and geotechnical investigations; Seismic survey airguns; Installation of material; Subsea pipeline; Subsea cables and ancillary equipment; Turbines
● Pollution	Wind farms create chemical, air, and sediment pollution and can produce waste that affects all animals and vegetation of the area	Fish: salmon, lamprey Crustaceans: white-clawed crayfish Molluscs	Species: medium to high, depending on the toxicity of pollutants and the vulnerability of affected species Ecosystem: medium, with potential cascading effects on ecosystem health	Immediate to localised, affecting water quality and sediment within the project vicinity	Construction; Decommissioning	Survey vessels; Turbine foundations; Cables; Subsea cable; Ancillary equipment
● Collision	Birds and bats collide with the wind turbines when using the area (usually as a migration route), while marine animals collide with vessels, especially during the construction phase	Birds: migratory birds, passerines Bats Marine mammals: sperm and baleen whales, seals, turtles	High, especially for migrating birds and large marine mammals	Immediate to localised, particularly around wind turbine locations.	Construction; Operation	Rotor blade; Turbines; Vessels
● Electromagnetic field (EMF) emission	EMFs are emitted from the cables connecting the wind turbines with the onshore grid and they may affect the behaviour of marine animals	Fish: sturgeon, migratory salmonids	Low, depending on sensitivity and range of detection	Immediate, around cable installations	Operation	Subsea cables

Environmental impact	Effect	Affected ecosystem elements	Potential magnitude of impact	Spatial extent of impact	Life-cycle stage where impact is most likely	Technology-specific cause
		Marine mammals: Harbor porpoise, seals				
● Habitat degradation	Offshore wind projects installations and activities can physically damage benthic habitats, resulting in habitat degradation and loss of biodiversity	Habitats: benthic habitats seagrass meadows, cold-water coral habitats	Medium to high, depending on the sensitivity of the habitat and extent of disturbance	Immediate to localised, around wind projects installations	Construction; Operation; Decommissioning	Turbine foundations; Subsea cables Tower
● Habitat loss and displacement of species	The physical presence of offshore wind projects can lead to habitat loss and displacement of wildlife, affecting breeding, feeding, and resting sites	Birds: kingfishers, gannets, puffins, breeding seabirds Marine mammals: seals, harbour porpoises, dolphins Benthic species: cold-water corals, bivalves, fish species	High, particularly for species relying on specific habitats.	Immediate to localised, around wind projects installations.	Construction; Operation	Turbine foundations; Subsea cables Tower
● Barrier effect	Offshore wind farms can act as barriers to the regular movements of birds, particularly during migration, leading to increased energy expenditure and potential disruptions to breeding and foraging behaviours	Birds: migrating birds, breeding seabirds	High, particularly for species with long migration routes.	Localised, along migration routes and breeding areas	Construction; Operation; Decommissioning	Wind farms
● Artificial reef effect / habitat creation	Offshore wind farms may create artificial habitats that attract certain species, potentially acting as sanctuaries for fish and benthic invertebrates	Fish and benthic invertebrates	Low to medium, with potential positive effects on local biodiversity	Localised	Construction; Operation	Turbine foundations

Legend: ● negative environmental impact ● potentially positive environmental impact

4.2.1. Noise

Underwater noise is created during several life-cycle stages of offshore wind power projects. During preliminary investigations into determining suitability of a site for offshore wind development, severe noise may be produced by seismic survey air guns[100]. During the construction phase, significant noise disturbance is created by the foundation pile driving and unintended unexploded ordnance (UXO) detonations[101,102]. During the operational phase, the noise is generated by the operation of the wind turbines; the origin can be either mechanical, i.e., noise produced by the gears bearing, power generator etc., or aerodynamical, i.e., caused by the airflow that passes through the turbines. While the wind project operates, vessel activity is a key source of noise pollution, as boats produce continuous noise from their propellers and engines[103]. Finally, in the decommissioning phase, noise is produced from vehicle and machinery operation during dismantling activities (e.g., cutting and drilling to remove/cut off subsea structures)[104].

The **effects** of underwater noise on marine mammals can be significant to lethal, including behavioural disturbance such as displacement, masking[105], temporary or permanent threshold shift[106], tissue damage and, in extreme cases where the animal is close to the pile driving activities, it can lead to death[107]. Dolphins, porpoises and cetaceans in general are particularly affected, since the underwater noise can interfere with their vocalisation and disrupt their communication, which can ultimately affect their ability to feed and to navigate. This impact occurs particularly during construction of an offshore wind project. Studies conducted in the Danish North Sea showed that during the construction of an offshore wind project, the acoustic activity of harbour porpoises was reduced for a mean distance of about 20 km, and it lasted for the entire five months of the construction[108]. The findings were confirmed by another study in the German North Sea, where the porpoise presence was reduced by 90% when noise levels surpassed 170 dB and by 25% for noise levels between 145 and 150 dB[109]. However, the magnitude of the disturbance depends on the local context and the level of the mammal population. For instance, in the North Sea the porpoise population is abundant while in the Baltic Sea the population is low, with near threatened conservation status, and fewer good-quality habitats. Therefore, the displacement of the porpoise from their primary habitat due to the noise in the Baltic Sea would have greater impact than in the North Sea[110]. Harbour porpoise is the only marine mammal found across the Baltic, North, and Mediterranean Seas, with other marine mammals presence depending on the ecosystem characteristic. For

[100] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Available at: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[101] European Commission, Directorate-General for Environment. (2020). Guidance document on wind energy developments and EU nature legislation. Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2779/457035.
[102] European waters have a high number of unexploded ordnance (UXO) as a result of the two World Wars, mine laying and naval battles over the last century. Unintended detonations of UXO can lead to series of shock waves with damaging results to the wind farms, the vessels, the animals and the personnel involved. To avoid that, project developers are surveying the development area to remove UXO items prior to construction. More information at: http://cdn.pes.eu.com/assets/misc_dec/unexplodedpdf-554410301279.pdf.
[103] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Available at: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[104] Ibidem.
[105] The process by which the threshold of hearing for one sound is raised by the presence of another (masking) sound (Erbe et al. 2015, Communication masking in marine mammals: A review and research strategy).
[106] Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS) are temporary and permanent hearing loss respectively, which are caused from exposure to extreme bouts of loud noise. See https://andersonaudiology.com/resources/what-is-temporary-threshold-shift-tts/#:~:text=Temporary%20Threshold%20Shift%20(TTS)%20is,ear%20can%20be%20pushed%20over.
[107] OSPAR. (n.d.). OSPAR Guidance on Environmental Considerations for Off-shore Wind Farm Development. Available at: https://www.vliz.be/imisdocs/publications/ocrd/224682.pdf.
[108] European Commission, Directorate-General for Environment. (2020). Guidance document on wind energy developments and EU nature legislation. Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2779/457035.
[109] Brandt, M. J., Dragon, A. C., Diederichs, A., Schubert, A., Kosarev, V., Nehls, G., ... & Piper, W. (2016). Effects of offshore pile driving on harbour porpoise abundance in the German Bight. Assessment of noise effects. Report by BioConsult SH, IBL Umweltplanung GmbH, and Institute of Applied Ecology (IfAO). Available at: https://tethys.pnnl.gov/sites/default/files/publications/Brandt-et-al-2016.pdf.
[110] European Commission, Directorate-General for Environment. (2020). Guidance document on wind energy developments and EU nature legislation. Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2779/457035.

example, grey seal, and ringed seal (critical status) in the Baltic Sea, grey and harbour seals, minke whale, white beaked dolphin in the North Sea, monk seal (endangered), fin whale, and common dolphin in the Mediterranean[111].

The effects of underwater noise on fish are notable if the offshore wind farm is developed in coastal or estuarine waters[112]. Literature suggests that fish with swim bladders, such as salmon and shad species, are more sensitive to sound pressure and therefore more impacted, compared to those with no swim bladder (e.g., lampreys) who are only sensitive to particle motion. The range of the disturbance effect depends on the type of fish and the activities, and can be up to about 15 km.

4.2.2. Pollution

Pollution associated with offshore wind power development can occur as:

- **Chemical pollution,** through the use of diesel lubricants, oil lubricants, hydraulic fluids, and anti-fouling compounds, paints, coverings, accidental spills from vessels[113,114,115].
- **Waste,** generated by construction activities, such as lubricants and concrete[116].
- **GHG and air pollutant emissions** in the atmosphere, due to the increased traffic of vessels during the construction phase[117].
- **Sediment pollution,** during the construction and operation phase of wind projects that may produce heavy metal pollutants; although this impact is considered limited[118].

Literature suggests that during the operational phase, some structures can include hazardous substances (e.g., indium, gallium, zinc and aluminium)[119]. The affected species from the pollution of air and water depend on the area of the development as well as from the type of substance. Species identified in literature include salmons, lampreys, white clawed crayfish and freshwater pearl mussels[120].

4.2.3. Collision

Collisions frequently occur during the operational phase of offshore wind and affects birds, bats and marine animals. Migrating birds, such as cranes and birds of prey, are the most affected and are at high risk of colliding with the wind turbines or the tower[121]. Griffon vultures (*Gyps fulvus*) are prone to collisions with wind turbines while foraging, with island populations (such as those found in the Mediterranean) especially vulnerable due to their low ability to

[111] Marine Information System for Europe. (n.d.). Marine Mammals. Available at: https://water.europa.eu/marine/state-of-europe-seas/state-of-biodiversity/marine-mammals.
[112] European Commission, Directorate-General for Environment. (2020). Guidance document on wind energy developments and EU nature legislation. Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2779/457035.
[113] Ibidem.
[114] OSPAR. (n.d.). OSPAR Guidance on Environmental Considerations for Off-shore Wind Farm Development. Available at: https://www.vliz.be/imisdocs/publications/ocrd/224682.pdf.
[115] Blæsbjerg, M., Pawlak, J., Sørensen, T.K., Vestergaard, O. (2009). Marine spatial planning in the Nordic region – Principles, Perspectives and Opportunities. Retrieved from: https://www.diva-portal.org/smash/get/diva2:701398/FULLTEXT01.pdf.
[116] Commission notice - Assessment of plans and projects in relation to Natura 2000 sites - Methodological guidance on Article 6(3) and (4) of the Habitats Directive 92/43/EU Commission – C(2021) 6913 final.
[117] Baltic Power. (2022). Environmental impact assessment report for the Baltic power off-shore wind farm. Retrieved from: https://balticpower.pl/media/1171/environmental-impact-assessment-report-for-the-baltic-power-offshore-wind-farm.pdf.
[118] Wang, T., Ru, X., Deng, B., Zhang, C., Wang, X., Yang, B., & Zhang, L. (2023). Evidence that offshore wind farms might affect marine sediment quality and microbial communities. Science of The Total Environment, 856, 158782. http://dx.doi.org/10.1016/j.scitotenv.2022.158782.
[119] Umweltbundesamt (2023) Overview of hazardous substances potentially emitted from offshore industries to the marine environment
[120] Commission notice - Assessment of plans and projects in relation to Natura 2000 sites - Methodological guidance on Article 6(3) and (4) of the Habitats Directive 92/43/EU Commission – C(2021) 6913 final.
[121] Swedish Agency for Marine and Water Management. (2023). Coexistence of offshore wind power with commercial fishing, aquaculture and nature conservation. Retrieved from: https://www.havochvatten.se/download/18.66b74fcf189fa80353f297a3/1692347346807/CoexistenceWithOff-shoreWind_EN.pdf.

cross the sea and thus avoid the wind farms[122]. However, these impacts depend on the proximity of wind farms to known nesting and breeding sites of the vultures. Seabird species, such as the European herring gull and the black-headed gull are also at high risk of collision during their migration. However, they have developed avoidance behaviour during active migration, as they tend to fly at lower heights (i.e., below the lowest tip of the blade) therefore lowering the collision risk[123]. A study published in 2023[124] found that seabirds, including Herring gulls, Gannets, Kittiwakes, Great black-backed gulls, tend to adapt to offshore wind farms and avoid collisions. The flight trajectory followed by these birds adapts to rotor blades from about 120m distance, and becomes increasingly precise when closer to the rotors. In particular, Herring gulls and Kittiwakes showed horizontal avoidance behaviour from 90-110 m and 140-160 m respectively, while Gannets sand Great black-backed gulls exhibited avoidance behaviour at 40 m and 60 m from the rotor blade tips.

Studies also suggest that bats might be affected during the migration period in spring and autumn as they move offshore, leading to similar effects observed for birds. Additionally, bats forage near wind turbines which may increase the risk of collision. However, the effects on the bats are not well studied and results are limited[125].

Poor weather conditions (e.g., storms, fog, low clouds) increase the risk of collision since they reduce visibility, and during these conditions birds tend to fly at lower altitudes[126]. Several studies also indicate that birds and bats are often attracted by the light emitted from the wind turbine towers especially during foggy nights[127,128].

Marine mammals' collisions are not related to the wind turbines per se, but rather to the maritime traffic in the open sea water, which is very frequent during construction and decommissioning phase. Literature[129] suggests that the collisions are more likely to occur with large species such as sperm and baleen whales, which may hit ships longer than 80 m. Wildlife in the Mediterranean (monk seal, common dolphin, fin whale), in the North Sea (harbour seal, harbour porpoise, white beaked dolphin, sperm whale, baleen whale), and in the Baltic Sea (harbour porpoise, grey and ringed seals)[130] is also likely to be highly affected since these sea areas already have human activity and ship traffic; increased construction activities to develop offshore wind farms will further congest the space available to marine mammals for movement[131].

4.2.4. Electromagnetic fields (EMF) emission

The AC and HVDC cables that are used to transmit electricity from the offshore turbines to the onshore grid emit electromagnetic fields (EMF), which in turn induce an electrical field in the marine environment[132]. The impact of EMF occurs during operation phase and it can influence

[122] Cerri J. et al. (2023). Griffon Vulture movements are concentrated around roost and supplementary feeding stations: implications for wind energy development on Mediterranean islands. Global Ecology and Conservation, Volume 47. https://doi.org/10.1016/j.gecco.2023.e02651.
[123] Swedish Agency for Marine and Water Management. (2023). Coexistence of offshore wind power with commercial fishing, aquaculture and nature conservation. Retrieved from: https://www.havochvatten.se/download/18.66b74fcf189fa80353f297a3/1692347346807/CoexistenceWithOff-shoreWind_EN.pdf.
[124] Vattenfall. (2023). Unique study: birds avoid wind turbine blades. Available at: https://group.vattenfall.com/press-and-media/newsroom/2023/unique-study-birds-avoid-wind-turbine-blades.
[125] Swedish Agency for Marine and Water Management. (2023). Coexistence of offshore wind power with commercial fishing, aquaculture and nature conservation. Retrieved from: https://www.havochvatten.se/download/18.66b74fcf189fa80353f297a3/1692347346807/CoexistenceWithOff-shoreWind_EN.pdf.
[126] Hamed, T. A., & Alshare, A. (2022). Environmental impact of solar and wind energy-a review. Journal of Sustainable Development of Energy, Water and Environment Systems, 10(2), 1-23. DOI: https://doi.org/10.13044/j.sdewes.d9.0387.
[127] Ibidem.
[128] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[129] European Commission, Directorate-General for Environment. (2020). Guidance document on wind energy developments and EU nature legislation. Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2779/457035.
[130] https://water.europa.eu/marine/state-of-europe-seas/state-of-biodiversity/marine-mammals.
[131] Ibidem.
[132] European Commission, Directorate-General for Environment. (2020). Guidance document on wind energy developments and EU nature legislation. Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2779/457035.

the behaviour and physiology of fish and other benthic organisms[133]. Studies indicate that sturgeon and migratory salmonids are able to detect EMF, in the latter case possibly affecting the returning route of the young fish to the adults[134]. The EMF effect in marine mammals such as harbour porpoise and seals seems to be insignificant, but the literature suggests that the effect needs to be studied further[135]. Findings are limited with regards to the range of the effect, but the EEA study[136] on environmental impacts of offshore energy indicates that they are limited to the vicinity of the cable.

4.2.5. Habitat degradation

Habitat degradation arises primarily from the physical presence of offshore wind farms and associated construction and operational activities, which can disturb and alter marine habitats. One major cause of habitat degradation is the installation and operation of wind turbines and associated infrastructure, which can lead to physical damage to benthic habitats and substrate through activities such as pile driving, dredging, and cable laying[137]. These disturbances can disrupt sediment stability, alter hydrodynamic processes, and modify habitat structure, resulting in habitat degradation and loss of biodiversity[138].

Several habitats in the European Union are particularly at risk of degradation due to offshore wind energy development. These include:

- **Benthic Habitats:** Seabed habitats such as sandbanks, gravel beds, and rocky reefs are susceptible to degradation because of wind farms' installation and operation activities, which can disturb substrate integrity and alter the benthic community structure [139,140].
- **Seagrass Meadows:** Coastal seagrass meadows are vulnerable to habitat degradation from changes in water quality, light availability, and sediment dynamics associated with offshore wind farm construction and operation[141].
- **Coral Gardens:** Cold-water coral habitats, such as those found in the North Atlantic, are at risk of degradation from physical damage and sedimentation resulting from wind farm activities[142].

The consequences of habitat degradation due to offshore wind energy development can be extensive. Alterations to benthic habitats can affect the distribution and abundance of associated species, leading to changes in community composition and ecosystem function[143].

[133] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Available at: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[134] European Commission, Directorate-General for Environment. (2020). Guidance document on wind energy developments and EU nature legislation. Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2779/457035.
[135] Ibidem.
[136] Galparsoro, I., Menchaca, I., Seeger, I., Nurmi, M., McDonald, H., Garmendia, J.M., Pouso, S., Borja, Á. (2022). Mapping potential environmental impacts of offshore renewable energy. ETC/ ICM Report 2/2022: European Topic Centre on Inland, Coastal and Marine waters, 123 pp. Retrieved from: https://www.eionet.europa.eu/etcs/etc-icm/products/etc-icm-reports/etc-icm-report-2-2022-mapping-potential-environmental-impacts-of-offshore-renewable-energy/@@download/file/02_2022_ETC%20ICM%20Report_Mapping%20potential%20environmental%20impacts%20of%20offshore%20renewable%20energy.pdf.
[137] IUCN (2021) Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers.
[138] Gill, A. B., et al. (2021). "The impact of offshore wind farms on the marine environment: a review." Environmental Research Letters, 16(2), 023002.
[139] Ibidem.
[140] European Commission, Directorate-General for Environment. (2020). Guidance document on wind energy developments and EU nature legislation. Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2779/457035.
[141] Orth, R. J., Carruthers, T. J., Dennison, W. C., Duarte, C. M., Fourqurean, J. W., Heck, K. L., ... & Williams, S. L. (2006). A global crisis for seagrass ecosystems. Bioscience, 56(12), 987-996. https://doi.org/10.1641/0006-3568(2006)56[987:AGCFSE]2.0.CO;2.
[142] Ragnarsson, S. Á., Burgos, J. M., Kutti, T., van den Beld, I., Egilsdóttir, H., Arnaud-Haond, S., & Grehan, A. (2017). The impact of anthropogenic activity on cold-water corals. *Marine Animal Forests: The Ecology of Benthic Biodiversity Hotspots*, 989-1023. DOI:10.1007/978-3-319-17001-5_27-1.
[143] Degraer, S., Brabant, R., Rumes, B. & Vigin, L. (eds). 2018. Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Assessing and Managing Effect Spheres of Influence. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, 136 p https://tethys.pnnl.gov/sites/default/files/publications/Degraer-et-al-2018_0.pdf.

Habitat degradation can trigger cascading effects throughout the food web, impacting trophic interactions and ecosystem dynamics.

4.2.6. Habitat loss and displacement of species

The loss of habitat primarily arises from the physical presence of offshore wind farms in areas that would otherwise be used by wildlife, therefore affecting birds and marine animals breeding, feeding and resting sites[144]. Seabird species such as Kingfishers living in coastal areas[145], Gannets (*Morus bassanus*) and Puffins (*Fratercula arctica*) that rely on coastal and offshore habitats for nesting and foraging are susceptible to habitat loss and displacement from wind farm infrastructure[146]. Marine mammals, such as seals (*Phoca spp*.), harbour porpoises (*Phocoena Phocoena*) and dolphins (Delphinidae) utilise coastal and offshore habitats for breeding, feeding, and resting, so any loss of habitat may affect their reproductive success and survival[147].

Construction activities such as pile driving, dredging, and cable laying can disrupt seabed habitats and alter sediment composition, affecting benthic communities and species reliant on these habitats for feeding, breeding, and shelter[148]. Organisms inhabiting the seabed, such as cold-water corals (e.g., *Lophelia pertusa*) and bivalves, are at risk of habitat loss[149]. For wind turbines installed in soft-bottom habitats, fish species that live in soft-bottom habitats can also be displaced[150]. The effects can be permanent or temporary displacement of the organisms.

Furthermore, the installation of foundations, scour protection and turbine towers can have hydrodynamic effects that may also cause changes in the habitat[151]. The installation of the transmission cables can also lead to habitat loss and degradation, and negatively affect marine animals. The impact is greater when the cables are installed below the seabed[152].

4.2.7. Barrier effect

The barrier effect is defined as the obstacle that a wind farm creates to the regular movements of animals, in particular birds (seabirds, coastal birds)[153]. Barrier effects occur during all stages of wind farm development causing prolonged impact on birds, but are especially present during the operation phase[154].

In essence, birds are required to fly around a wind park, which results in additional energy expenditure. While the detour is potentially small compared to the whole migration route, in cases of multiple wind parks it can be extended to multiple kilometres, therefore causing a significant cumulative effect[155]. For instance, the North Sea is a migration area for millions of

[144] European Commission, Directorate-General for Environment. (2020). Guidance document on wind energy developments and EU nature legislation. Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2779/457035.
[145] Ibidem.
[146] Garthe, S., Schwemmer, H., Peschko, V. et al. Large-scale effects of offshore wind farms on seabirds of high conservation concern. Sci Rep 13, 4779 (2023). https://doi.org/10.1038/s41598-023-31601-z.
[147]Carstensen J. et al (2006). Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). Marine Ecology Progress Series. 321:295-308 doi:10.3354/meps321295.
[148] The term benthic refers to anything associated with or occurring on the bottom of a body of water.
[149] Willsteed, E., Gill, A. B., Birchenough, S. N., & Jude, S. (2017). Assessing the cumulative environmental effects of marine renewable energy developments: Establishing common ground. Science of the Total Environment, 577, 19-32. https://doi.org/10.1016/j.scitotenv.2016.10.152.
[150] Methratta, E. T., & Dardick, W. R. (2019). Meta-analysis of finfish abundance at offshore wind farms. Reviews in Fisheries Science & Aquaculture, 27(2), 242-260. doi.org/10.1080/23308249.2019.1584601.
[151] Ibidem.
[152] Commission notice - Assessment of plans and projects in relation to Natura 2000 sites - Methodological guidance on Article 6(3) and (4) of the Habitats Directive 92/43/EU Commission – C(2021) 6913 final.
[153] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[154] Ibidem.
[155] Swedish Agency for Marine and Water Management. (2023). Coexistence of offshore wind power with commercial fishing, aquaculture and nature conservation. Retrieved from: https://www.havochvatten.se/download/18.66b74fcf189fa80353f297a3/1692347346807/CoexistenceWithOff-shoreWind_EN.pdf

birds during spring and autumn via two main routes: the east-west from mainland to the British Isles and the north-south from Scandinavia to the English Channel or the south of Europe[156].

Besides migrating birds, breeding seabirds may be highly affected by offshore wind development, since they are forced to make repeated diversions from and to the nests and the foraging areas[157]. However, in both cases, the barrier effect is highly dependent on seasonality (for instance higher in spring when birds are usually nesting) and location.

Regarding marine mammals, literature suggests that the barrier effect is absent in certain species (such as harbour porpoises and harbour seals) while for others (such as fin whales and sperm whales) there is insufficient information to arrive at definitive conclusions[158].

4.2.8. Artificial reef effect / habitat creation

While the installation of wind turbines in soft sediments may lead to displacement of fish that use soft-bottom habitats[159], installing wind turbines in hard sediments has the potential to attract benthic invertebrates and hence provide forage for several fish species; however there is a chance of attracting non-native species, locally rare species and habitat-forming species, which may disrupt the biodiversity of the area[160]. A study published by the University of Ghent[161] showed that development of offshore wind in the North Sea produced artificial reefs that created an enabling environment for flatfish (plaice), including due to the installation of scour protection in the foundations. However, not all fish in all wind development areas necessarily react the same way, and additional research is required to better understand these impacts (named sanctuary effect). The RECON project investigated the effects of wind farms in the North Sea ecosystem, and found that 95 different species had found shelter in the artificial structures created on the wind farms researched[162].

Depending on the country and the regulations concerning offshore wind farm sites, wind farms can become marine species sanctuaries, as other activities are often significantly reduced or limited within the wind farm area[163,164].

4.3. Main environmental impact of solar energy technologies

Ground-mounted photovoltaic systems (PVs) use solar panels to convert sunlight directly into electricity; they often require large land areas, leading to habitat degradation, fragmentation, and altered microclimates. The environmental impacts can manifest across diverse ecosystems, and affect species such as birds, mammals, insects, and aquatic organisms.

[156] https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/ecology/offshore-wind-ecological-programme-wozep/birds/.
[157] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/457041.
[158] Ibidem.
[159] Methratta, E. T., & Dardick, W. R. (2019). Meta-analysis of finfish abundance at offshore wind farms. Reviews in Fisheries Science & Aquaculture, 27(2), 242-260. doi.org/10.1080/23308249.2019.1584601.
[160] Degraer, S., Carey, D. A., Coolen, J. W., Hutchison, Z. L., Kerckhof, F., Rumes, B., & Vanaverbeke, J. (2020). Offshore wind farm artificial reefs affect ecosystem structure and functioning. Oceanography, 33(4), 48-57.
[161] Buyse, J. (2023). Ecological impacts of offshore wind farms on flatfish with emphasis on plaice Pleuronectes platessa, a species of commercial interest in the southern North Sea. Ghent University. Faculty of Sciences, Ghent, Belgium. Retrieved from: http://hdl.handle.net/1854/LU-01GY7FNGWVPTVXHGXVZEZES2QB.
[162] Coolen, J. W. P. (Ed.), Jak, R. G. (Ed.), van der Weide, B. E., Cuperus, J., Luttikhuizen, P., Schutter, M., Dorenbosch, M., Driessen, F., Lengkeek, W., Blomberg, M., van Moorsel, G., Faasse, M. A., Bos, O. G., Dias, I. M., Spierings, M., Glorius, S. G., Becking, L. E., Schol, T., Crooijmans, R., ... Lindeboom, H. J. (2018). RECON: Reef effect structures in the North Sea, islands or connections? Summary report. (Wageningen Marine Research rapport; No. C074/17A). Wageningen Marine Research. https://doi.org/10.18174/424244.
[163] Blæsbjerg, M., Pawlak, J., Sørensen, T.K., Vestergaard, O. (2009). Marine spatial planning in the Nordic region – Principles, Perspectives and Opportunities. Retrieved from: https://www.diva-portal.org/smash/get/diva2:701398/FULLTEXT01.pdf.
[164] Buyse, J. (2023). Ecological impacts of offshore wind farms on flatfish with emphasis on plaice Pleuronectes platessa, a species of commercial interest in the southern North Sea. Ghent University. Faculty of Sciences, Ghent, Belgium. Retrieved from: http://hdl.handle.net/1854/LU-01GY7FNGWVPTVXHGXVZEZES2QB.

Addressing these challenges requires comprehensive assessment and management strategies tailored to the specific characteristics of this technology, to mitigate negative effects on ecosystems and safeguard environmental sustainability.

A summary of the main environmental impacts of solar PVs is provided in the table below, followed by a discussion of these impacts.

Table 4-5 Summary of main solar energy environmental impacts

Environmental impact	Effect	Affected ecosystem elements	Potential magnitude of impact	Spatial extent of impact	Life-cycle stage where impact is most likely	Technology-specific cause
Wildlife mortality and injury	Solar PV systems can cause wildlife mortality and injury through, collision, electrocution, and attraction	Mammals, birds (larger prey hunting birds, water birds), bats	Medium	Immediate	Operation; Construction	Reflective PV surfaces; Grid connection infrastructure, incl. power lines
Changes in the microclimate	Solar PV systems can alter surrounding microclimates through heating or shading effects, impacting vegetation and biodiversity	Ecosystem: vegetation (arid and grasslands) Species: invertebrates, insects, microorganisms	Medium	Immediate to localised	Operation	Ground mounted PV panels; Infrastructure
Habitat degradation	Solar PV systems can damage ecosystems through habitat loss, degradation and fragmentation, affecting vegetation, soil, water quality, and biodiversity	Habitats: arid and semi-arid, agricultural land, grasslands, steppe	High, particularly for habitats directly occupied by solar facilities.	Immediate to extended, affecting areas directly occupied by solar plants as well as surrounding ecosystems	Construction; Operation; Decommissioning	Power plant facilities; Access to location; Preparation of site for installation (i.e., removal of vegetation)
Habitat loss, creation and displacement of species and barrier effect	Potential impacts include functional habitat fragmentation, dispersal limitations, population isolation and displacement, and altered habitat quality. In some cases, habitat creation occurs in the form of nesting grounds, shelters and feeding or foraging grounds. Barrier effects occur	Mammals: e.g., mule deer, reindeer, wild boars and bears Birds: ground-nesting migratory birds, common ravens Foraging animals	High, especially for species reliant on specific habitats or migration routes.	Immediate to extended, affecting areas occupied by solar facilities and beyond	Construction; Operation; Decommissioning	Power plant infrastructure (panels, mounting equipment); Protective fences around power plant; Access to location

Environmental impact	Effect	Affected ecosystem elements	Potential magnitude of impact	Spatial extent of impact	Life-cycle stage where impact is most likely	Technology-specific cause
	when elements are constructed (e.g. buildings, fences) which block the movement and seasonal migration of wildlife					

Legend: ● negative environmental impact, ● possible positive environmental impact

4.3.1. Wildlife mortality and injury

Wildlife can experience disorientation, serious injuries or even death because of solar PV systems' impacts. These can be broadly grouped in the following categories: collision, entrapment, electrocution, and attraction.

Collision is particularly relevant for species that are unable to detect or avoid structures such as power lines, infrastructure and PV panels[165]. There is some evidence that the reflective surfaces on buildings and PV panels increase the risk of collision[166].

The risk of **electrocution** is related to grid connection infrastructure during the operation phase of solar plants, particularly for birds and bats, including medium and large-bodied species such as raptors. Electrocution risk is especially pronounced on pylons of medium and high-voltage lines, where birds may perch for hunting or nesting. Factors influencing the risk of electrocution include the structure and configuration of pylons, the size of the bird, and landscape characteristics. In areas with few natural perches, birds may be more likely to use artificial ones, increasing their exposure to electrocution risk.

In certain cases, animals can be **attracted** to different components of the solar energy facilities. Attraction can occur due to microclimatic conditions, cover, enhanced prey density, lighting and confusion of visual cue[167]. The so-called 'lake effect' hypothesis states that water birds can mistake the surface of PV panels for water bodies and attempt to land on them, leading to injuries. Aquatic insects also appear to be attracted by the panels, which can lead to maladaptive behaviour such as laying their eggs on the panels, where they will not hatch[168]. Solar facilities can provide high quality habitat for certain non-native species, especially urban adapted species, which may negatively affect local species[169].

4.3.2. Changes in the microclimate

Solar PV systems can, during the operation phase, cause changes to their surrounding microclimate, which in turn can have an impact on vegetation and biodiversity. These changes can be induced by either a heating effect or a shading effect, and can manifest as shading, altered temperature and changed rainfall distribution (with effects on soil moisture). PV panels operate at an average temperature of 50°C, and in extreme cases can reach a temperature of 70°C, which heats the air around the system during the day[170]. This **heating effect** can influence the thermal comfort conditions and generate a heat island effect, potentially leading to the burning of birds and insects[171]. At night, PV panels absorb heat and have a radiative cooling effect on the surrounding environment.

[165] Hamed, T. A., & Alshare, A. (2022). Environmental Impact of Solar and Wind Energy - A Review. Retrieved from: https://doi.org/10.13044/j.sdewes.d9.0387 and European Commission. (2020). Potential impacts of solar, geothermal and ocean energy on habitats and species protected under the habitats and birds directives – Final report. Retrieved from: https://data.europa.eu/doi/10.2779/784760.

[166] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.

[167] Chock, R. Y., Clucas, B., Peterson, E. K., Blackwell, B. F., Blumstein, D. T., Church, K., ... & Toni, P. (2021). Evaluating potential effects of solar power facilities on wildlife from an animal behavior perspective. Conservation Science and Practice, 3(2), e319. Retrieved from: https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.319.

[168] European Commission. (2020). Potential impacts of solar, geothermal and ocean energy on habitats and species protected under the habitats and birds directives – Final report. Retrieved from: https://data.europa.eu/doi/10.2779/784760.

[169] Chock, R. Y., Clucas, B., Peterson, E. K., Blackwell, B. F., Blumstein, D. T., Church, K., ... & Toni, P. (2021). Evaluating potential effects of solar power facilities on wildlife from an animal behavior perspective. Conservation Science and Practice, 3(2), e319. Retrieved from: https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.319.

[170] Baggio, N. (n.d.) What is the temperature coefficient of a photovoltaic panel? FuturaSun. Retrieved from: https://www.futurasun.com/en/temperature-coefficient/#:~:text=Often%2C%20the%20module%20runs%20at,more%20than%20the%20reference%20conditions.

[171] Hamed, T. A., & Alshare, A. (2022). Environmental impact of solar and wind energy-a review. Journal of Sustainable Development of Energy, Water and Environment Systems, 10(2), 1-23. DOI: https://doi.org/10.13044/j.sdewes.d9.0387.

Solar panels can create shade and induce a so-called **shadow effect**. This alters the composition and diversity of species in the habitats underlying them due to changes in the air and soil[172]. For instance, the obstruction of light and rainfall causes the underlying soil to degrade, hindering the growth of vegetation[173].

Changes to the microclimate can also have a **positive impact**, creating a conducive environment for certain fauna and flora which thrive in shade[174]. This can increase the plant species diversity and soil microorganisms in grasslands (e.g. increased presence of Proteobacteria, Acidobacteriota, and Methylomirabilota)[175]. Shadow effect, in case of co-location of the PV power plant and agriculture, can help preserve vegetation such as agricultural crops which grow under the panels and protect them during heatwaves and periods of drought[176].

4.3.3. Habitat degradation

The biggest impact on habitats and species of large-scale solar PV parks could come from the **direct land occupancy** of the plant itself. The affected habitats can be faced with reduced vegetation cover, compaction of soil, reduced infiltration, increased runoff, decreased soil activity, decreased soil organic matter, and impaired water quality[177].

Construction of PV plants and the associated facilities could require the **removal of vegetation and surface grading** across large areas of land. This has the potential of causing habitat loss, degradation and fragmentation, leading to a reduction in species richness and density. During the operation of the solar power plants, vegetation management is often undertaken underneath and in the gaps between solar panels. Vegetation is kept under control using herbicides, covering the ground with gravel or frequent mowing[178].

Ground-mounted solar energy plants usually require larger areas of land per unit across the whole life cycle than industrial-sized wind plants[179]. Additionally, once solar plants are installed, they can impact the **fertility and landscape of the land used**, and compete with land-use for agricultural purposes[180]. The usage of land for solar facilities can lead to reduced access to, or even the loss of, provisioning services, such as those provided by agriculture and natural resources. However, the specific ecosystem service impact is not yet well understood and requires particular attention in early planning. Increasingly, practices are being developed to combine solar energy systems with the preservation of agricultural yields and grazing areas (agrivoltaics) to reduce the competition of solar PV with agriculture[181].

Soil loss is another potential negative effect from the construction of solar energy systems. In arid or semi-arid regions, which are well suited for the development of solar energy, the

[172] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[173] European Commission. (2020). Potential impacts of solar, geothermal and ocean energy on habitats and species protected under the habitats and birds directives – Final report. Retrieved from: https://data.europa.eu/doi/10.2779/784760.
[174] Ibidem.
[175] Bai, Z., Jia, A., Bai, Z., Qu, S., Zhang, M., Kong, L., ... & Wang, M. (2022). Photovoltaic panels have altered grassland plant biodiversity and soil microbial diversity. Frontiers in Microbiology, 13, 1065899. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9797687/.
[176] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[177] European Commission. (2020). Potential impacts of solar, geothermal and ocean energy on habitats and species protected under the habitats and birds directives – Final report. Retrieved from: https://data.europa.eu/doi/10.2779/784760.
[178] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[179] Our World in Data (2022). How does the land use of different electricity sources compare?. Retrieved from: https://ourworldindata.org/land-use-per-energy-source.
[180] Hamed, T. A., & Alshare, A. (2022). Environmental impact of solar and wind energy-a review. Journal of Sustainable Development of Energy, Water and Environment Systems, 10(2), 1-23. DOI: https://doi.org/10.13044/j.sdewes.d9.0387.
[181] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.

desert vegetation is responsible for regulating the movement of sand, dust, and sediments. The activities that can take place during the construction and operation of solar energy plants, such as the removal of vegetation, grading of the land or construction of roads, can alter the location and composition of vegetation, thus decreasing their regulating function. This means that soil is not retained when storms or floods happen[182].

4.3.4. Habitat loss, creation and displacement of species

The construction and operation of solar facilities may directly or indirectly alter habitat use in highly biodiverse ecosystems via functional habitat fragmentation, dispersal limitations, population isolation and displacement, and altered habitat quality. For foraging animals, the changes to the habitat can alter the available cues and the predation risk assessment, which disrupts the normal foraging patterns of animals. The degradation can cause animals to stay away from their previous habitats and alter their population dynamics and reproduction patterns. This can have a cascade effect on populations beyond the site boundaries, leading to reduced food web integrity and altered species' interaction[183].

A potential **positive environmental impact** from the construction of solar energy plants is the **creation of new habitats**. Since a new structure is built and the surrounding environment is adapted to accommodate it, space is created for the development of new habitats such as nesting grounds, shelters and feeding or foraging grounds[184]. Specifically, PV panels can provide a shelter for animals against their aerial predators. Facility buildings and fences can serve as escape routes for smaller prey, since they exclude larger terrestrial predators. The polarised light created by PV panels attracts polarotactic organisms such as insects (as mentioned under Section 4.3.1) which can benefit insectivorous species due to increased availability of prey. However, at the same time, avian species collision risk increase, due to reflective surfaces, and they may face increased competition for food.

4.3.5. Barrier effect

Barrier effects occur when **wildlife movements, including local and seasonal migration, are blocked or restricted,** whether on a localised scale or over longer distances. The barrier effect is especially relevant for large scale solar PV infrastructures. The impacts are not only related to the solar panels, but also to the grid connection, co-located storage, and access to the location. For instance, the construction of high voltage transmission lines may cause the displacement of wildlife, the removal of vegetation, or the introduction of invasive alien species, degrading the habitat's quality[185].

Related to the access to the location, **security fences** are usually installed around the perimeter of the power plant. These fences pose the greatest threat to large mammal movement and/or migrations, since smaller mammals can often still pass under them through ground clearance or through gaps in the fence weave[186]. Some examples of species that are particularly affected by constructed barriers are mule deer, reindeer, wild boars and bears.

[182] Ibidem.
[183] Bai, Z., Jia, A., Bai, Z., Qu, S., Zhang, M., Kong, L., ... & Wang, M. (2022). Photovoltaic panels have altered grassland plant biodiversity and soil microbial diversity. Frontiers in Microbiology, 13, 1065899. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9797687/.
[184] European Commission. (2020). Potential impacts of solar, geothermal and ocean energy on habitats and species protected under the habitats and birds directives – Final report. Retrieved from: https://data.europa.eu/doi/10.2779/784760.
[185] Hamed, T. A., & Alshare, A. (2022). Environmental impact of solar and wind energy-a review. Journal of Sustainable Development of Energy, Water and Environment Systems, 10(2), 1-23. DOI: https://doi.org/10.13044/j.sdewes.d9.0387.
[186] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.

The fragmentation of their habitat can lead to an impediment in the gene flow of the species[187]. Barriers to wildlife movement may lead to a depletion of feeding and resting places and genetic isolation of populations[188]. Additionally, if the sites are built on nesting areas of ground-nesting migratory birds, these birds may lose access to their nesting grounds, indirectly causing a decrease in their population.

4.3.6. Other environmental impacts

4.3.6.1. Pollution

In general, besides increased polarised light levels and some waste, operational solar PV plants generate limited amounts of pollution, largely associated with site maintenance. Construction, decommissioning and repowering of solar PV plants can lead to **dust, waste, noise and light pollution**[189].

The construction and operation of PV energy systems can involve soil grading and herbicide use, leading to air, soil and water **pollution**. This in turn can lead to increased mortality rates for organisms who live in the habitat, and potential extinction of native species.

The construction activities for the access to the location, the energy plant and accompanying facilities all create significant amounts of **dust and particle emissions**, especially in desert and arid regions. These dust emissions can have an adverse effect on plant fertility, water retention potential of soil, photosynthetic processes and water consumption of vegetation. Specifically, for vegetation, dust can cause root exposure, burial of plants and scratching of leaves and stems[190].

Noise pollution can cause certain animal species to avoid the solar plant and its facilities during the construction, operation and decommissioning; however this impact is almost negligible during the operational phase. Fauna can also be affected by road noise from traffic related to the plant. **Light pollution** comes from the light systems installed at the site and which are active during the operation, as well as the polarised light being reflected by the PV panels[191].

4.3.6.2. Pressure on water availability

Water can be used in several ways by solar energy plants. During the construction of solar energy plants, water channels are sometimes created to protect the facilities against floods. The channels have the purpose of **diverting surface water** away from the structures which can influence the flow of water and water availability in the larger area. Especially in ecosystems which are already facing water scarcity such as semi-arid ecosystems, the impact on the availability of water can be significant[192].

[187] Bai, Z., Jia, A., Bai, Z., Qu, S., Zhang, M., Kong, L., ... & Wang, M. (2022). Photovoltaic panels have altered grassland plant biodiversity and soil microbial diversity. Frontiers in Microbiology, 13, 1065899. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9797687/.
[188] European Commission. (2020). Potential impacts of solar, geothermal and ocean energy on habitats and species protected under the habitats and birds directives – Final report. Retrieved from: https://data.europa.eu/doi/10.2779/784760.
[189] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[190] Ibidem.
[191] Chock, R. Y., Clucas, B., Peterson, E. K., Blackwell, B. F., Blumstein, D. T., Church, K., ... & Toni, P. (2021). Evaluating potential effects of solar power facilities on wildlife from an animal behavior perspective. Conservation Science and Practice, 3(2), e319. Retrieved from: https://conbio.onlinelibrary.wiley.com/doi/10.1111/csp2.319.
[192] Hamed, T. A., & Alshare, A. (2022). Environmental impact of solar and wind energy-a review. Journal of Sustainable Development of Energy, Water and Environment Systems, 10(2), 1-23. DOI: https://doi.org/10.13044/j.sdewes.d9.0387.

Furthermore, the operation of solar energy plants might require water for **cleaning the panels** and decreasing dust infiltration. In arid and semi-arid areas, highly suitable to solar power plants due to their high solar radiance, water use by the energy systems could create competition and conflict with agricultural and domestic needs[193]. The use of manual dry brushing methods can help reduce water usage[194].

4.4. Cumulative impacts

Cumulative effects in the context of renewable energy development refer to the combined impacts of multiple projects of the same or different technologies occurring simultaneously within a specific geographic area. While each individual renewable energy project may have its own set of environmental impacts, cumulative effects arise when these projects coalesce, amplifying their collective influence on ecosystems, species, and habitats[195].

Cumulative effects can occur as spatial or temporal accumulation, with the latter being less studied and understood (and consequently not addressed here)[196]. Spatial accumulation refers to the overlapping effects of disturbances within a geographic area, leading to cumulative change due to insufficient space between disturbances for the environment to recover adequately. This phenomenon occurs across various scales and is often characterised by structural impacts such as habitat fragmentation and population shifts.

Cumulative effects arise from the interaction of all developments that occur in the same space; this can then include cumulative effects of a renewable energy plant and any other development unrelated to the renewable energy plant taking place nearby. Here, we focus on recognising key cumulative effects that arise from development of multiple projects of the same technology type (e.g., impacts from a suite of onshore wind power projects) as well as projects developed across different technologies (e.g., impacts associated with development of solar PV and wind power in the same areas).

The scale and magnitude of specific impacts will depend on the characteristics of the area, the resilience of resident fauna, and the intensity of activities. The most significant cumulative impacts associated with offshore wind, onshore wind and solar energy can be grouped into the following impact categories:

- **Habitat degradation and loss.** As multiple onshore wind farms, offshore wind farms, and solar energy facilities are constructed and operated in close proximity, the cumulative effect on habitat degradation and loss becomes more pronounced. The combined removal of vegetation, compaction of soil, and fragmentation of habitats can lead to significant disruption in local ecosystems, further exacerbating the impact on various species and ecosystems. Additionally, the collective footprint of these projects may result in the loss of larger contiguous areas of habitat, reducing overall biodiversity and ecological resilience.
- **Barrier effects and habitat fragmentation.** When wind turbines and solar panels are installed across landscapes and seascapes, along with associated infrastructure such as roads and transmission lines, the barrier effect on wildlife movement intensifies with the clustering of multiple renewable energy projects. This cumulative barrier effect can disrupt natural migration routes, fragment habitats, and isolate populations of various species. Moreover, the co-location of different renewable energy technologies in the

[193] Ibidem.
[194] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[195] Ibidem.
[196] Willsteed, E., Gill, A. B., Birchenough, S. N., & Jude, S. (2017). Assessing the cumulative environmental effects of marine renewable energy developments: Establishing common ground. *Science of the Total Environment*, 577, 19-32. https://doi.org/10.1016/j.scitotenv.2016.10.152.

same area can compound these effects, amplifying the challenges faced by wildlife navigating the altered landscape.

- **Wildlife mortality and injury.** The cumulative impact of wildlife mortality and injury from collisions with wind turbine blades, entrapment in solar energy facilities, and other hazards becomes more significant as the number of onshore and offshore wind farms and solar installations increases. The clustering of these projects heightens the risk to various species, particularly those sensitive to disturbance or habitat alteration. Greater concentrations of renewable energy infrastructure can increase the risk of collisions and create larger barriers for wildlife movement or migration, potentially leading to population declines and ecosystem imbalances.
- **Pollution.** The cumulative pollution generated by construction activities, maintenance operations, and accidental spills associated with onshore wind energy, offshore wind energy, and solar energy can have far-reaching consequences on soil, water, and air quality. As multiple renewable energy projects are developed within the same region, the collective impact on environmental pollution intensifies, posing risks to both terrestrial and aquatic ecosystems. This cumulative pollution may impair ecosystem function, degrade habitat quality, and jeopardise the health of resident species, compounding the ecological challenges faced by affected ecosystems.

4.5. Non-environmental considerations

Beyond their environmental impacts, renewable energy projects have significant societal implications that shape local communities, economies, and cultural landscapes. Understanding these broader impacts is crucial for assessing the overall sustainability and acceptance of renewable energy deployment. This section explores key non-environmental effects by examining both the positive and negative dimensions of these impacts.

Socio-economic aspects. The construction and operation of offshore wind, onshore wind, and solar energy projects can lead to socio-economic displacement of local communities due to changes in land use, infrastructure development, and workforce dynamics. This displacement may result in loss of livelihoods, cultural disruption, and demographic shifts in affected areas (e.g., relocation of fishing communities or changes in traditional agricultural practices). Furthermore, regions heavily reliant on renewable energy production may become economically dependent on the sector, leading to vulnerabilities associated with fluctuations in energy markets, policy changes, and technological advancements. This dependence may lead to vulnerabilities, affecting local economies, employment patterns, and investment strategies. For instance, sudden shifts in government subsidies or changes in energy policies can have ripple effects on communities dependent on renewable energy, potentially leading to job losses or economic instability. On the positive side, renewable energy projects can stimulate economic growth by creating jobs, attracting investment, and boosting local economies[197]. These projects can contribute to long-term sustainability and resilience, enhancing the overall well-being of communities.

Additionally, the deployment of renewable energy fosters innovation and investment in related industries, anchoring regional economies, attracting skilled labour, and spurring technological innovation[198,199]. Moreover, by diversifying the energy mix and reducing dependence on fossil fuels, renewable energy projects enhance energy supply security, stability, and improve the

[197] IRENA and ILO (2023), Renewable energy and jobs: Annual review 2023, International Renewable Energy Agency, Abu Dhabi and International Labour Organisation, Geneva. Retrieved from: https://www.irena.org/Publications/2023/Sep/Renewable-energy-and-jobs-Annual-review-2023.

[198] Ibidem.

[199] Muro, M., Rothwell, J., & Saha, D. (2011). Sizing the Clean Economy: A National and Regional Green Jobs Assessment. Brookings Institution. Retrieved from: https://www.brookings.edu/articles/sizing-the-clean-economy-a-national-and-regional-green-jobs-assessment/.

trade balance, contributing to long-term economic resilience and the overall socio-economic stability of communities.

Public health considerations. The construction and operation of renewable energy projects may raise public health concerns related to noise pollution, electromagnetic fields, and occupational hazards associated with maintenance and operation activities. Some examples of such effects include sleep disturbances, stress, and annoyance associated with noise or shadow flickering from wind turbines[200, 201]. Health concerns can contribute to community opposition, public anxiety, and demands for health impact assessments and monitoring programs. The body of knowledge on assessing the impacts of renewable energy projects on human health is evolving. For example, the Netherlands analysed all scientific literature published between 2017 and 2020 to study the impacts of noise from wind turbines on human health; the study showed clear evidence that the sound produced by wind turbines results in annoyance, but found no clear evidence of sleep disturbance[202]. Despite health concerns, renewable energy projects generally have lower negative environmental and health impacts compared to fossil fuel-based energy generation. Transitioning to renewable energy sources can help mitigate air and water pollution, reduce the burden of diseases such as respiratory illnesses and cardiovascular diseases. The deployment of renewable energy technologies contributes to climate change mitigation, which is crucial for safeguarding public health in the long term. Research has shown that the health benefits of transitioning to cleaner energy sources outweigh the potential risks associated with their implementation[203].

Visual and aesthetic considerations. The installation of wind turbines and solar panels can alter the visual landscape of coastal and terrestrial environments, impacting scenic views and cultural heritage sites. These changes may lead to aesthetic degradation and reduce the attractiveness of natural landscapes, potentially affecting tourism and recreational activities in affected areas. On the other hand, renewable energy projects can enhance the aesthetic value of landscapes, becoming symbols of sustainability and technological innovation. Studies have shown that the public perception of renewable energy aesthetics can improve over time as communities become accustomed to the presence of clean energy infrastructure[204].

[200] Turunen, A. W., Tiittanen, P., Yli-Tuomi, T., Taimisto, P., & Lanki, T. (2021). Self-reported health in the vicinity of five wind power production areas in Finland. *Environment international*, 151, 106419. https://doi.org/10.1016/j.envint.2021.106419.
[201] Karasmanaki E. (2022). Is it safe to live near wind turbines? Reviewing the impacts of wind turbine noise. *Energy for Sustainable Development69*, 87-102. https://doi.org/10.1016/j.esd.2022.05.012.
[202] National Institute for Public Health and the Environment. (2023). Factsheet on wind turbines and health. Retrieved from: https://www.rivm.nl/windenergie/windmolens-gezondheid (in Dutch only).
[203] Clean Technica. (2019). Health Benefits of Renewable Energy Far Outweigh The Costs, Say MIT Researchers. Retrieved from: https://cleantechnica.com/2019/08/16/health-benefits-of-renewable-energy-far-outweigh-the-costs-say-mit-researchers/.
[204] Firestone J. et al. (2018) Reconsidering barriers to wind power projects: community engagement, developer transparency and place. *Journal of Environmental Policy & Planning,* 20:3, 370-386, DOI: 10.1080/1523908X.2017.1418656.

5. Mitigating environmental impacts of RAAs

In order to designate Renewables Acceleration Areas (RAAs), Member States will have to prepare a plan or plans for RAAs for one or more types of renewable energy sources. A part of this plan (or plans), according to the Article 15(c)(1)(b) of the revised RED, is a '**mitigation rulebook'** outlining rules for ensuring effective mitigation of environmental impacts that a specific renewable energy technology might have in a particular RAA.

When adopting the mitigation rulebook, Member States need to ensure that the rules set out in it are:

1. Comprehensive and robust, applying to the installation of renewable energy plants, co-located energy storage facilities, as well as assets necessary for their connection to the grid;
2. Targeted to the specifics of the designated area, selected technologies and identified environmental impacts. Where appropriate, those measures should ensure compliance with requirements of directives relevant for environment and biodiversity protection, namely the Birds[205], Habitats[206] and Water Framework[207] Directives.

Pursuant to Article 15c(4)(b) of the revised RED, once an RAA plan is developed, including the proposed mitigation rulebook, it must undergo a **Strategic Environmental Assessment (SEA)**. In case of likely significant impacts on Natura 2000 sites, the appropriate assessment in line with the Article 6(3) of the Habitats Directive must be done as well.

The aim of this approach is to frontload the assessment of possible environmental impacts of renewable energy projects in specific areas and to identify appropriate and proportionate mitigation measures that developers of projects located in the RAAs will need to implement. This will simplify and accelerate the assessment of the individual projects to be located in RAAs, for which a simpler and shorter screening mechanism will be implemented, according to Article 16a(4) and (5) of the revised RED. Depending on the results of the screening, additional specific mitigation measures may be required for certain projects within the RAA.

5.1. Developing the mitigation rulebook

The mitigation rulebook should consider the impact of all projects that may be installed in an RAA and establish rules on mitigation measures to address the impacts of the expected number of projects in the RAA. **The measures identified in the rulebook should, therefore, be applicable to all projects (and ancillary equipment).** Additional mitigation measures that may result from screening of individual projects within an RAA fall outside of the rulebook's scope.

5.1.1. Mitigation measures

Environmental impacts of renewable energy projects can occur at all project stages, from project construction to operation to decommissioning. Managing these impacts should, therefore, take place during all project stages. However, a project that considers its environmental footprint in the design stage can lead to fewer impacts happening at later stages, consequently requiring less mitigation efforts to be undertaken.

[205] Directive 2009/147/EEC on the conservation of wild birds (codified version).
[206] Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.
[207] Directive 2000/60/EC establishing a framework for Community action in the field of water policy

Table 5-1 Summary of potential environmental impacts, grouped per affected elements of ecosystem

	Onshore wind	Offshore wind	Solar
Wildlife mortality and injury	• Collision • Electrocution	• Collision	• Collision • Electrocution • Attraction
Habitat loss	• Barrier effect • Habitat loss and displacement of species	• Barrier effect • Habitat loss and displacement of species	• Barrier effect • Habitat loss and displacement of species
Ecosystem degradation	• Habitat degradation • Noise	• Habitat degradation • Noise • Pollution • EMF emission	• Habitat degradation • Changes in microclimate

Mitigation measures are any procedure or action undertaken to avoid or reduce the adverse impacts that a project or activity may have on the environment[208]. They are usually planned through a hierarchical approach of (1) **avoidance**, and (2) **minimisation to prevent or reduce negative impacts from taking place.** Such an approach to mitigation is integrated in the EU legislation requiring assessment of impacts, i.e., Habitats Directive[209] and EIA Directive[210].

In the context of RAAs, the goal is to ensure up-front mitigation of environmental impacts **by avoidance and minimisation measures**. Certain measures to restore temporarily affected work areas during construction and decommissioning may be considered under mitigation measures, as well as measures to restore the areas after decommissioning (see for example Box 8).

Mitigation measures should be devised in the planning stage, when it is still possible to apply an iterative approach to deciding which measures to implement, based on their effectiveness and proportionality. The ultimate goal is to select those measures that will effectively mitigate negative impacts, caused by the operation of a renewable power plant and all activities associated with its construction and decommissioning, without making the overall project technically and economically unfeasible.

A variety of measures are possible, from consideration of how to organise work (e.g., setup of the construction site) and the design of the project (e.g., orientation of infrastructure), to concrete activities that will actively minimise impacts or restore areas. While selected in the planning stage, most mitigation measures are implemented in construction, operation and decommissioning stages. Figure 5-1 provides a visual representation of which mitigation measures are implemented and take effect across the project life-cycle stages.

[208] https://www.eionet.europa.eu/gemet/en/concept/5311.
[209] Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.
[210] Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment.

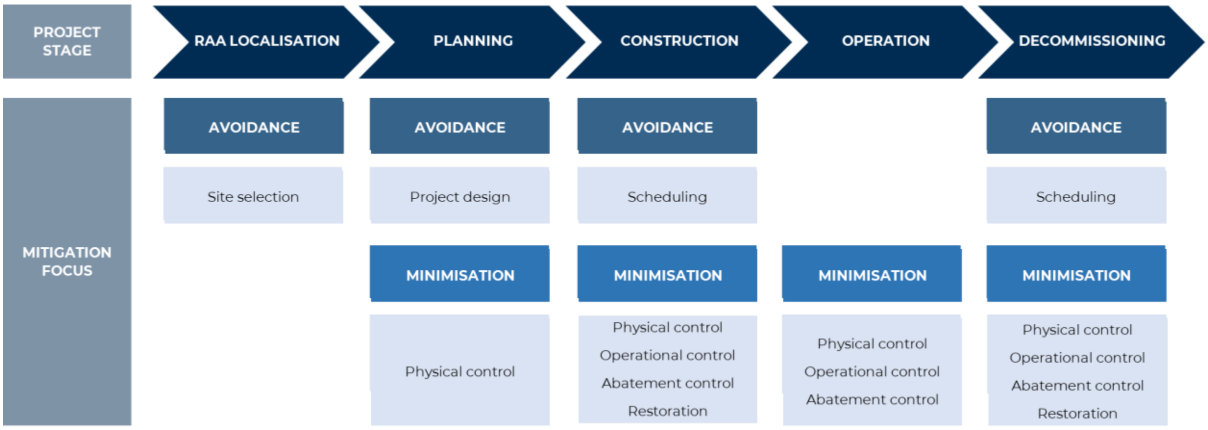

Figure 5-1 Implementation of avoidance and minimisation across project life cycle[211]

Mitigation measures are usually not mutually exclusive, but can be applied concurrently, in a synergistic approach that leads to more successful mitigation. However, these may also result in economic impacts for the project (cost increase, and potentially slower construction time).

Avoidance measures constitute the first and the most important step to mitigating environmental impacts, as they aim to completely circumvent or abstain from actions that can have negative effects. These measures can be grouped in the following categories:

- **Avoidance through site selection** implies locating the project away from areas of high environmental and biodiversity value. The methodology for identifying RAAs, which exclude environmentally high-value areas from consideration, is based on this mitigation measure.
- **Avoidance through project design** is achieved by adjusting the type of infrastructure, and its placing on the project site and mode of operation. Impacts can be avoided through adapted placement and orientation of infrastructure (e.g., wind turbines, power lines), and through the careful choice of construction and operational methods.
- **Avoidance through scheduling** implies adjusting the timing of project development/decommissioning activities in reference to ecosystem and biodiversity conditions on the site. Impacts can be avoided by accounting for seasonal and diurnal patterns of species behaviours (e.g., breeding, migrating), and ecosystem functioning (e.g., vegetation growth cycle).

Minimisation measures are taken to reduce the duration, intensity and/or extent of impacts that cannot be completely avoided. They are identified during the design stage, but are implemented throughout the whole project cycle. There are three types of mitigation measures:

- **Physical controls.** Adapting the design or operation to reduce impacts (e.g., bird flight diverters on power lines, curtailment of wind turbine operations);
- **Operational controls**. Managing and regulating actions of people associated with the project development;
- **Abatement controls**. Actions to reduce levels of pollutants (e.g. emissions of dust, light, noise), either from being produced or transmitted wider into the environment.

Minimisation measures can overlap, and often more than one is needed to successfully achieve mitigation. If not well-conceived at the design stage of project development,

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

minimisation measures may fail in the implementation phase, requiring adjustments or additional measures to be applied.

5.1.2. Applying mitigation measures to RAAs

5.1.2.1. Appropriate site selection for RAA

The appropriate site selection is the first – and key – mitigation measure, as it reduces overall environmental impact of a Renewables Acceleration Area (RAA), and the need for mitigation measures.

Built into the process of identifying RAAs are environmental considerations – the RAAs cannot be designated in areas of high environmental values (e.g., Natura 2000 sites, protected areas, major bird and marine mammal migratory routes and other sensitive sites). Instead, RAAs must be located on sites with lower environmental sensitivity where no significant environmental impacts are expected, such as degraded sites or areas that are already developed or in some other use (if co-location is possible, based on type of renewable technology). **Selection of RAA sites,** following these environmental stipulations and as methodologically outlined in Chapter 3, **constitutes the application of the first mitigation measure – avoidance through site selection**.

While applying the RAA methodology will ensure that selected sites are of lower environmental significance, there may still be impacts that need to be mitigated. **Appropriate avoidance and minimisation measures should be planned as part of the operationalisation of an RAA site**[212].

5.1.2.2. Understanding environmental impacts

Selecting which mitigation measures to apply starts with first identifying which impacts can materialise based on the planned siting of an RAA, in relation to the wider environmental / ecosystem conditions and the type of renewable energy projects to be developed. Broadly, impacts can be grouped in the following categories (further detailed in Chapter 4):

- wildlife mortality and injury
- loss of habitat
- ecosystem degradation.

Grouping of impacts into broader categories will provide a comprehensive picture of all impacts in an RAA that can lead to the same result (e.g., loss of habitat), thus i) ensuring that no impact is overlooked when mitigation is designed, while ii) enabling the consideration of whether multiple impacts could be addressed by a single mitigation measure.

This grouping can also help to understand which type of impacts are more likely to occur (i.e., more impacts are expected in the ecosystem degradation category), which could then be prioritised for mitigation.

If the RAA is located in the proximity of areas of high biodiversity significance, or in areas likely to affect them (e.g., Natura 2000 site, wildlife sensitive areas, such as those for nesting, breeding or foraging of protected species, or major wildlife migratory routes), relevant potential impacts on these species and habitats should be carefully considered to determine if the Appropriate Assessment under Article 6 of the Habitats Directive may be required. For these

[212] In this context, operationalisation means development of project(s) of appropriate renewable technology within a designated RAA site.

situations, the Appropriate Assessment should provide detailed information on possible impacts.

5.1.2.3. Selecting mitigation measures

Once impacts have been identified, they should be matched with possible mitigation measures taking care to:

- Prioritise avoidance, then minimisation of impacts when considering options. As far as possible, the mitigation rulebook should consist of a mix of measures from these two categories.
- Consider restoration[213] for residual impact of activities linked to the operationalisation of an RAA site, and which cannot be mitigated earlier in the process.

Making the final selection of the mitigation measures should be done with consideration of their proportionality and appropriateness with regards to achieving the desired objective – mitigation of one or more environmental impacts. Therefore, selected measures should be:

- Suitable for mitigating identified environmental impacts, considering the type of renewable technology and the location of the project;
- Appropriate to ensure that no significant environmental impacts are expected in the designated RAA site;
- Feasible for implementation considering required resources and timing available for application of the measure; and
- Viable in ensuring that maximum benefits are achieved while not compromising the feasibility of renewable energy projects.

The following elements should be considered when deciding the final selection of mitigation measures:

A) Suitability of measures

- **Mitigation of environmental impact.** Selected mitigation measures should, if possible, eliminate or mitigate all or most of the identified environmental impact. Restoration should be considered to manage any residual impacts that could not be addressed through avoidance and minimisation.
- **Technical viability.** Selected mitigation measures should be effectively implementable from an engineering or technical standpoint. For example, if a mitigation measure involves the installation of noise reduction technologies around wind turbines, technical viability would consider factors such as the compatibility of these technologies with the wind turbine designs, their effectiveness in reducing noise levels, and any potential impact on turbine performance.

B) Feasibility of measures

- **Compliance with regulations and standards.** Selected mitigation measure should meet regulatory requirements and environmental standards governing environmental protection. If the measure requires specific approvals / permits (e.g., novel measures), the timeline of this permitting process should be carefully investigated to determine if it aligns with the overall timeline for an RAA designation (as per Article 15c of the revised RED).

[213] Not to be confused with the compensatory measures required under Article 6(4) of the Habitats Directive.

- **Resource availability**. Resources necessary for implementation of the mitigation measure should be easily accessible and sufficient. Resources to consider include availability of materials, specialised equipment, skilled labour, logistical support, and funding.

- **Time required for implementation.** The timeline for implementing the mitigation measure should be aligned with the overall RAA designation planning and deadlines as stipulated in the revised RED (Article 15c). Some mitigation measures may require significant planning and preparation, while others may be more straightforward to implement. Factors such as regulatory approvals, procurement of materials, construction timelines, and coordination with other project activities would influence the time required for implementing mitigation measures.

C) Viability of measures

- **Cost-effectiveness.** The cost of applying a selected mitigation measure should be commensurate with the reductions achieved in environmental impacts. While a full cost-benefit analysis (CBA) is not required, the cost of any measure to be implemented, should be proportional to the benefits of the project. Measures that will mitigate impacts in the most cost-effective way should be prioritised.

- **Synergies.** Potential synergies and trade-offs between different mitigation measures should be investigated in order to identify opportunities to implement complementary measures that maximise environmental benefits while minimising negative impacts on other aspects of the environment.

- **Sustainability.** Selected mitigation measure should be resilient to changing environmental conditions, climate variability, and anthropogenic pressures in order to ensure maintaining environmental benefits over time.

Considering the above elements, avoidance and minimisation measures should be selected and prioritised based on the following criteria:

1. Mitigation measures **fully, or to the largest extent, address the expected environmental impacts** in an RAA.

2. Mitigation measures **address the most significant environmental impacts** of an RAA site.

3. Mitigation measures are **proven and tested**, as they will require less (if any) permitting compared to new, innovative solutions which may be subject to additional approvals. Novel measures whose effectiveness has not been widely tested can be applied **on a pilot basis and for a limited time period**, only if a monitoring programme is implemented, and immediate steps are taken if they prove to be ineffective.

4. Mitigation measures **can be integrated into the RAA schedule** without causing delays or disruptions to the overall schedule for designation of an RAA, as required under Article 15c of the revised RED. This includes measures that are aligned with the regulatory requirements, as well as those for which adequate resources are available for seamless application.

5. Mitigation measures are **proportionate** to achieve their objective (e.g. if measures that do not require curtailment are considered effective, they should be prioritised for projects in an RAA, subject to monitoring of their effectiveness).

6. Mitigation measures **address more than one impact** simultaneously or address same impact across multiple project life cycle stages.

Monitoring and evaluation is key to determining the effectiveness of the mitigation measure over time. Monitoring protocols to track environmental indicators and measure progress towards achieving mitigation goals should be set up, and used to regularly assess progress. In case measures prove ineffective or insufficient, they should be adapted or new ones developed.

Engagement with stakeholders and monitoring can help to ensure that mitigation measures are robust and comprehensive, leading to the successful achievement of the purpose of RAAs. To that end, the following should be considered as good practice approaches:

- **Engaging relevant experts, including project developers** to predict environmental impacts and help design mitigation measures. These experts can be engaged through the entire process, or brought in at specific stages to move along the process of determining mitigation measures (e.g., deciding between avoidance and minimisation measures).
- **Engaging with wider stakeholders** early in the design process to co-develop mitigation approaches, as this could also alleviate any potential opposition to the designation of an RAA site and increase the sense of ownership of the process.
- **Educating and training project staff** (construction, maintenance, decommissioning teams) to ensure they understand and adhere to the mitigation measures. This can be achieved by preparing detailed guidelines on behaviour for project staff (e.g., waste management protocols) also outlining activities that are forbidden/illegal (e.g., hunting and killing of wildlife) and establishing protocols for addressing unexpected impacts or ecological incidents (including who to notify and how to report on them)[214].

5.1.3. Mitigating cumulative impacts

In the context of RAAs, cumulative impacts may arise from interactions of multiple projects within the same RAA, as well as their interaction with other developments not related to the projects themselves in the area.

Mitigation of cumulative impacts should also prioritise avoidance and minimisation as the preferred approaches, with restoration applied only in case of residual impacts[215]. Planning and application of efforts to mitigate cumulative impacts should happen concurrently with mitigation of other impacts. In addition to cost-efficiency, this is required to ensure that selected measures are effective and lead to successful mitigation.

In practical terms, this means that the selection of mitigation measures should also be informed by their effectiveness in addressing cumulative impacts (i.e., separate process to determine measures to mitigate cumulative impacts should be avoided, unless such impacts become evident during the later stage of project implementation).

Key practical considerations for mitigating cumulative impacts include:

- Planning process needs to account not only for project-specific impacts, but also consider the project's contribution to cumulative impacts[216].
    - Specify design requirements of projects within RAA to avoid cumulative impacts (e.g., design, timing, technology).

[214] Ibidem.
[215] International Finance Corporation. (2013). Good Practice Handbook: Cumulative Impact Assessment and Management: Guidance for the Private Sector in Emerging Markets.
[216] Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers. Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy.

    - Require adaptive management of minimisation measures of individual projects within RAA to ensure flexibility in case of emerging cumulative impacts through new project developments.

- Cumulative impacts may extend beyond the boundary of an RAA, in interaction with other developments present in the area. For example, noise and vibration coming from the interaction of offshore wind energy farms and shipping activities happening in the same areas may have cumulative effects[217]. In such cases:
    - When selecting an RAA site, consider other developments and activities present in the area, determine if any interaction of environmental impacts is possible, and assess the magnitude and scale of such combination.
    - Collaboratively engage with stakeholders responsible for concurring activities to develop joint impact management strategies.
    - Consider a joint monitoring programme to assess the success of mitigation of cumulative impacts, and to support any revision/update to agreed mitigation measures.

[217] Willsteed E. at al (2017). Assessing the cumulative environmental effects of marine renewable energy developments: Establishing common ground. Science of The Total Environment, Volume 577, Pages 19-32, Available at: https://doi.org/10.1016/j.scitotenv.2016.10.152.

5.2. Mitigation measures to avoid and minimise impacts of onshore wind

This section presents and discusses the application of mitigation measures to minimise the impacts of onshore wind projects according to the project phase.

Table 5-2 Mitigation measures to avoid and minimise impacts of offshore wind projects

Impact category	Impact	Mitigation measure	Type of mitigation measure	Planning	Construction	Operation	Decommission
Wildlife mortality and injury	Collision	Micro siting (M[218])	Avoid - design				
		Re-route high voltage lines (M)	Avoid - design				
		Use of (audio, visual) deterrents (M)	Minimise – physical control				
		Buffer zones	Avoid - design				
		Decrease attraction factors for bats	Minimise – physical control				
		Design transmission lines to reduce the risk of collision	Minimise – physical control				
		Schedule construction activities to avoid ecologically sensitive periods	Avoid – scheduling				
		Increase visibility of overhead transmission lines	Minimise – physical control				
		Management and modification of adjacent habitats	Minimise – physical control				
		Increase the cut-in speeds	Minimise – physical control				
	Collision, electrocution	Re-route, mark or bury powerlines (M)	Minimise – physical control				
	Electrocution	Insulate power lines	Minimise – physical control				
		Design transmission lines to discourage birds to perch	Minimise – physical control				

[218] Measures that can be applied to mitigate multiple impacts are denoted with a letter M in parentheses.

Impact category	Impact	Mitigation measure	Type of mitigation measure	Planning	Construction	Operation	Decommission
		Use of (audio, visual) deterrents (M)	Minimise – physical control				
Habitat loss	Barrier effect	Micro-siting / increase spacing between turbines, or clustering of wind turbines (M)	Avoid - design				
		Re-route, mark or bury powerlines (M)	Minimise – physical control				
	Habitat loss	Restrict the extent of road network	Minimise – physical control				
	Displacement of species	Curtail wind turbine operations	Minimise – operational control				
Ecosystem degradation	Habitat degradation	Manage and regulate contractor activity and movement	Minimise – operational control				
		Implement soil erosion and sedimentation control measures	Minimise – physical control				
		Install sufficient drainage works under all access roads	Minimise – physical control				
		Prevent the introduction and spread of invasive species	Minimise – abatement control				
		Limit clearance of natural vegetation	Minimise – physical control				
		Protect existing vegetation through physical barriers	Minimise – physical control				
	Pollution	Implement protocol for rapid management for any chemical leaks or spills	Minimise – abatement control				
	Noise	Alternative operational modes	Minimise – physical control				
		Alternative turbine technology	Minimise – physical control				
		Alternative construction methods	Minimise – abatement control				

5.2.1. Planning stage

5.2.1.1. Collision

Reducing the risk of bird and bat collision with wind turbines and associated infrastructure can be facilitated in the planning phase through the following measures:

- **Micro-siting** entails optimising the placement of individual wind turbines and grid connection infrastructure based on site-specific conditions, in order to reduce the collision risk.
- **Re-routing of high voltage lines** such as running overhead transmission lines along existing linear elements, e.g. row of trees, transport infrastructure and existing power lines etc.
    - *RAA site located near a major bird migratory route*
      If the site is located near a bird migration route, the alignment of turbines may be adjusted so that it operates parallel to, and not across the general flight directions or other movements such as between roosting, nesting and feeding areas[219].
- **Buffer zones** can be established to reduce collision risk with bats, especially if habitats associated with higher levels of bat activity are present in the vicinity of wind farm. Such habitats include large hedgerows or treelines; broadleaved or coniferous woodlands or woodland edges; single mature trees, particularly when suitable for roosts; watercourses, ponds or lake shores; and buildings (occupied or derelict, including bridges and mines) where suitable for roosts[220]. In these cases, siting a small wind turbine at least 25 metres away from habitats may reduce collision risk.
- **Designing transmission lines to reduce the risk of collision**, by making early decisions on:
    - reducing the number of vertical wire levels;
    - keeping overhead wires low, span lengths short;
    - using thick cabling to increase visibility.

5.2.1.2. Electrocution

- **Designing transmission lines to discourage birds to perch** entirely, or at least close to, energised wires, can be achieved by adding cross-arms and insulators. Nonetheless, it is also important to mention that no insulation is 100% safe for birds, especially as such installations experience wear and tear in the long term. Practical examples of different mitigation designs are available in literature such as *Electrocutions & Collisions of Birds in EU Countries,* that was published in 2022 by BirdLife[221].

[219] Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers. Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy. https://doi.org/10.2305/IUCN.CH.2021.04.en.
[220] Rodrigues, L., Bach, L., Dubourg-Savage, M. J., Karapandža, B., Kovač, D., Kervyn, T., ... & Minderman, J. (2015). Guidelines for consideration of bats in wind farm projects: Revision 2014. EUROBATS Publication Series No. 6 (English version). UNEP/EUROBATS Secretariat, Bonn, Germany, 133 pp. Available at: https://www.eurobats.org/sites/default/files/documents/publications/publication_series/pubseries_no6_english.pdf.
[221] Electrocutions & Collisions of Birds in EU Countries: The Negative Impact & Best Practices for Mitigation. (2022). Compiled by Raptor Protection of Slovakia. Available at: https://www.birdlife.org/wp-content/uploads/2022/10/Electrocutions-Collisions-Birds-Best-Mitigation-Practices-NABU.pdf.

5.2.1.3. Habitat loss and barrier effect

- **Micro-siting** entails optimising the placement of individual wind turbines based on the site-specific natural configuration, in order to reduce the collision risk (as well as other environmental impacts such as the barrier effect[222], displacement[223], and habitat loss). For example, by increasing spacing between turbines, or clustering of wind turbines to create flight corridors for birds, especially if the project is located in the vicinity of migratory routes or hunting / foraging grounds.
- **Re-routing, marking or burying power lines**, including those used for grid connection:
    - *Re-routing* entails placing power lines outside the path of migratory corridors or other sensitive areas. This is especially relevant for RAAs that may be designated in proximity to migratory routes and sensitive areas, or in case they are located on an artificial and built surfaces within a Natura 2000 area (especially if the Natura 2000 site has been designated for bird and bat protection);
    - *Marking* involves the attachment of markers in the form of spirals, plates, flappers, swivels or spheres to overhead transmission lines to increase visibility[224];
    - *Burying* means that the power lines are buried beneath the soil, thereby no longer forming an obstacle to wildlife. This should be done only if it can be carried out without significantly affecting biodiversity and local habitats with the ground works.
- **Restricting the extent of road network** to be built for wind power development will ensure lower fragmentation of habitat, thus reducing barrier effects and habitat loss. In addition, it will limit traffic and extent of human disturbance to the species present on site overall[225].

5.2.2. Construction stage

5.2.2.1. Collision

- **Reducing the attraction factor to bats** to prevent and reduce collisions can be achieved by:
    - turning off security lights at the construction site at nighttime, or using lights only when absolutely necessary (for safety reasons), and lights that do not attract insects;
    - preventing water retention and growth of weeds / shrubs and any new shrub growth in the immediate area of wind turbine construction sites, i.e. including wind turbine operation zones and access roads etc.[226];

[222] Barrier effect refers to the hindrance to movement for birds and terrestrial species due to closely-spaced wind turbines and associated infrastructure.
[223] Displacement refers to reduced animal presence (such as birds, bats and terrestrial mammals) in and around wind farms due to habitat loss or disturbance.
[224] Bernardino, J., Bevanger, K., Barrientos, R., Dwyer, J. F., Marques, A. T., Martins, R. C., … Moreira, F. (2018). Bird collisions with power lines: State of the art and priority areas for research. Biological Conservation, 222, 1–13. doi:10.1016/j.biocon.2018.02.033.
[225] Ferrão da Costa, G., Paula, J., Petrucci-Fonseca, F., & Álvares, F. (2018). The indirect impacts of wind farms on terrestrial mammals: insights from the disturbance and exclusion effects on wolves (Canis lupus). Biodiversity and Wind Farms in Portugal: Current knowledge and insights for an integrated impact assessment process, 111-134.
[226] Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers. Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy. https://doi.org/10.2305/IUCN.CH.2021.04.en.

- ensuring good waste management practices are established to minimise the wind farm's attractiveness to scavenging birds at high collision risk such as vultures.

- **Scheduling of construction activities** to avoid, reduce and/or minimise disturbance during ecologically sensitive periods, for example avoiding, reducing, or phasing construction activities during ecologically sensitive periods, avoiding migration, breeding, feeding, and hibernation seasons, and considering diurnal/nocturnal movement patterns of concerned species present in the habitat, could also help to mitigate collision risks. Examples of considerations to be taken into account when scheduling such activities are:
  - avoiding the vicinity of occupied hibernacula and nursery roosts and the time of year when they are used;
  - avoiding the time of day and year when bats (and birds) are actively foraging and commuting;
  - phasing activities so that the entire site is not subjected to disturbance at the same time[227].

5.2.2.2. Barrier effect

- **Scheduling of construction activities** can also be applied to reducing the barrier effect during construction phase, for example avoiding, reducing, or phasing construction activities during ecologically sensitive periods, avoiding migration, breeding, feeding, and hibernation seasons, and considering diurnal/nocturnal movement patterns of concerned species present in the habitat[228].

5.2.2.3. Noise

- **Alternative construction methods** could be considered, which should also be supported by predictive noise modelling. For example, replacing the use of percussive pile driving with a non-metallic 'dolly' between the hammer and the driving helmet may reduce the noise levels and disturbance to birds. Other construction methods may avoid percussive, startling noise by using vibration to drive or screw piles (continuous flight augur) into the ground[229].

5.2.2.4. Habitat degradation

Reducing impact of construction activities on the quality and integrity of habitats can be achieved by:

- **Managing and regulating contractor activity and movement**, including
  - limiting work vehicles and machinery to designated construction and access areas only;

[227] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/457035, and Rodrigues, L., Bach, L., Dubourg-Savage, M. J., Karapandža, B., Kovač, D., Kervyn, T., ... & Minderman, J. (2015). Guidelines for consideration of bats in wind farm projects: Revision 2014. EUROBATS Publication Series No. 6 (English version). UNEP/EUROBATS Secretariat, Bonn, Germany, 133 pp. Available at: https://www.eurobats.org/sites/default/files/documents/publications/publication_series/pubseries_no6_english.pdf.

[228] Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers. Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy. https://doi.org/10.2305/IUCN.CH.2021.04.en.

[229] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020. https://data.europa.eu/doi/10.2779/457035.

  - limiting natural vegetation clearance to the minimum necessary during construction works.

- **Technical abatement measures** to minimise erosion and loss of vegetation, such as:
  - installing sufficient drainage works under all access roads, to reduce freshwater habitat fragmentation, avoid flooding land and damaging nearby waterbodies;
  - protecting existing vegetation through the establishment of exclusion zones using fencing / barriers;
  - implementing soil erosion and sedimentation control measures.

- **Preventing the introduction and spread of invasive species** on and off the construction site, for example, by inspecting and washing all equipment and vehicles before they enter and leave the construction site, managing storm and wastewater on site to avoid contamination and spreading of invasive species, using weed-free fill material etc.

Box 8 – Restoration

Carrying out **restoration** of temporary project footprint should be done as soon as possible using site-specific, indigenous and non-invasive species[230]. Examples of good restoration practices include:

- revegetating temporary-use and lay-down areas as soon as reasonably practicable after construction activities are complete;
- separately retaining and storing topsoil and sub-soil stripped from the construction areas, for later use during reinstatement;
- using site-specific, indigenous and non-invasive species for landscaping and rehabilitation works; and
- using soil, mulch and vegetation debris (that contains natural seed stock) to facilitate natural revegetation of disturbed areas, where reasonably practicable.

Restoration can be implemented in a phased approach, concurrent with construction activities, to enable recovery of temporary project footprint areas to its original condition and function as soon as possible.

5.2.3. Operational stage

5.2.3.1. Collision

- **Use of deterrents -** devices installed on site that emit audio or visual stimuli to deter birds from approaching too close to the wind turbines. Such stimuli can be produced either constantly (e.g., alarm and distress calls, low-frequency infrasound, and pulsating lights to deter nocturnal migrants), or intermittently when triggered by a bird detection system[231].
  - Passive deterrents such as painting the blades and turbine towers to increase visibility could also be applied, although they are not legally allowed in some

[230] Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers. Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy. https://doi.org/10.2305/IUCN.CH.2021.04.en.
[231] Examples of such installations may be found here: https://www.dtbird.com/index.php/dtbird-dtbat-document-downloads.

EU countries[232]. The efficacy of painting the blade of wind turbines to increase visibility and reduce avian collisions was found to be positive in a study at the wind power plant in Norway,[233] and further studies are being carried out in the Netherlands at the time of writing of this report[234].

- **Management and modification of adjacent habitats** (for example through land use or management practices) could reduce the suitability of a wind farm site for foraging and nesting, and may define guiding flight paths to reduce crossing frequency, without increasing environmental impacts[235]. New off-site fallows and hedgerows may move foraging areas, and bat-boxes and/or restoration of off-site roosting habitats may help to reduce bat presence and activity in the wind farm area[236].
- **Increasing the cut-in speeds** (the speed at which wind turbines become operational) can help reduce the risk of collision for bats that are foraging near / in the wind farm site[237]. Below cut-in speed, turbine blades either stop rotating, or feather – spin very slowly with no energy output. Determining threshold cut-in speed depends on various factors, and requires site-specific monitoring data on:
    - Wind speed (m/s measured at nacelle height),
    - Time after sunset / before sunrise,
    - Month of the year,
    - Ambient temperature, and
    - Precipitation (mm per hour)[238].

Box 9 – Blade feathering to mitigate bat collision risk

In Wallonia, blade feathering is implemented at sites where sensitive bat species are detected, which considers the various factors listed above. Between April to October, when air temperature is higher than 8°C (or 10°C in lowlands), and in the absence of rain, blade feathering is implemented when wind speed is below 6 m/s (measured at nacelle height) for six hours from sunset. During the autumn migration, i.e. between August to mid-October, blade feathering is implemented between sunset and sunrise when air temperature is higher than 5°C (or 8°C in lowlands), and when wind speed is below 7 m/s[239].

[232] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020. https://data.europa.eu/doi/10.2779/457035.
[233] May, R., Nygård, T., Falkdalen, U., Åström, J., Hamre, Ø., & Stokke, B. G. (2020). Paint it black: Efficacy of increased wind turbine rotor blade visibility to reduce avian fatalities. Ecology and evolution, 10(16), 8927-8935
[234] https://www.tno.nl/en/newsroom/2023/11/black-blades-windturbines/.
[235] Bernardino, J., Bevanger, K., Barrientos, R., Dwyer, J. F., Marques, A. T., Martins, R. C., … Moreira, F. (2018). Bird collisions with power lines: State of the art and priority areas for research. Biological Conservation, 222, 1–13. https://doi.org/10.1016/j.biocon.2018.02.029.
[236] Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers. Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy. https://doi.org/10.2305/IUCN.CH.2021.04.en.
[237] Rodríguez-San Pedro, A., Allendes, J. L., Bruna, T., & Grez, A. A. (2024). Species-Specific Responses of Insectivorous Bats to Weather Conditions in Central Chile. *Animals: an open access journal from MDPI*, *14*(6), 860. https://doi.org/10.3390/ani14060860.
[238] Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., Carbone, G. (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Guidelines for project developers. Gland, Switzerland: IUCN and Cambridge, UK: The Biodiversity Consultancy. https://doi.org/10.2305/IUCN.CH.2021.04.en.
[239] Bach, L., Dubourg-Savage, M. J., Karapandža, B., Kovač, D., Kervyn, T., ... & Minderman, J. (2015). Guidelines for consideration of bats in wind farm projects: Revision 2014. EUROBATS Publication Series No. 6 (English version). UNEP/EUROBATS Secretariat, Bonn, Germany, 133 pp. Available at: https://www.eurobats.org/sites/default/files/documents/publications/publication_series/pubseries_no6_english.pdf.

RAAs located near important habitats for birds and bats

If an RAA is located adjacent or close to important habitats for birds and bats, collision risks may be mitigated by implementing **temporary shutdown** of wind turbine operations, which could either be scheduled or carried out on-demand.

- Scheduled shutdowns are more efficient and effective for species with more predictable activity and migratory patterns. The schedule could consider some or all of the following:
    - Time of the day / night, which could influence bird / bat activities;
    - Ambient environmental factors, for example wind speeds and temperature – these are particularly relevant for preventing bat collisions;
    - Season, i.e. migration seasons.
- On-demand shutdown of turbines in real time, which can be carried out in response to a predetermined set of criteria based on the potential occurrence of high-risk scenarios, e.g. spotting large flocks of migratory birds approaching a wind farm.

Anti-collision technology, such as radar systems, can also be used to trigger curtailment.

Box 10 – Technologies for temporary curtailment of wind turbines

On demand shutdown of wind turbines is usually applied at sites where at-risk species have been identified, where wind project operations can be temporarily halted to mitigate the collision risk of birds and bats. Various technologies have been developed to mitigate collision risk. For example, DTBird® detects avian activity and independently mitigates collision risk by activating warning sounds and/or stopping the wind turbine[240].

In Germany, several federal states have applied turbine specific curtailment algorithms to stop the operations of turbines at times of high predicted collision risk and low energy production, which were developed based on multifactorial models[241]. German researchers have also developed a free software 'ProBat' to calculate the curtailment algorithms, although its applicability and accuracy for other European areas would need to be tested[242].

The adoption of algorithm-based curtailment which considers various factors, instead of a blanket curtailment which is based on wind speed and temperature thresholds, has also shown to be more efficient in reducing bat collision risk while maintaining the same energy production[243].

5.2.3.2. Electrocution

- **Insulation of power lines** - The installation of plastic hoods, silicon tubes, long rod insulators, plastic insulators to cover the metal consoles can offer safety to birds that

[240] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020. https://data.europa.eu/doi/10.2779/457035.
[241] Bach, L., Dubourg-Savage, M. J., Karapandža, B., Kovač, D., Kervyn, T., ... & Minderman, J. (2015). Guidelines for consideration of bats in wind farm projects: Revision 2014. EUROBATS Publication Series No. 6 (English version). UNEP/EUROBATS Secretariat, Bonn, Germany, 133 pp. Available at: https://www.eurobats.org/sites/default/files/documents/publications/publication_series/pubseries_no6_english.pdf.
[242] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020. https://data.europa.eu/doi/10.2779/457035.
[243] Barré, K., Froidevaux, J. S., Sotillo, A., Roemer, C., & Kerbiriou, C. (2023). Drivers of bat activity at wind turbines advocate for mitigating bat exposure using multicriteria algorithm-based curtailment. Science of the Total Environment, 866, 161404. https://doi.org/10.1016/j.scitotenv.2023.161404.

perch on overhead transmission lines and can mitigate the risk of electrocution of birds and bats.

Box 11 – 'SafeLines4Birds' project[244]

Project 'SafeLines4Birds' aims to reduce the non-natural mortality of 13 representative bird species around power lines. The project was launched in March 2023 and will run until 2028. It is expected that it will produce new knowledge that could be applied to mitigate risk of electrocution for birds.

5.2.3.3. Barotrauma

- **Use of deterrents** - installation of devices that emit audio or visual stimuli to deter bats from approaching too close to the wind turbines. These devices can produce stimuli either constantly (e.g., alarm and distress calls, low-frequency infrasound, and pulsating lights to deter nocturnal migrants), or intermittently when triggered by bat detection system [245].

5.2.3.4. Habitat loss and displacement of species

- **Curtailment of wind turbine operations**, which could either be scheduled or carried out on-demand (following a predetermined set of criteria based on the potential occurrence of high-risk scenarios), can mitigate the risk of displacement of wildlife, especially during ecologically sensitive periods, e.g. if the site is located adjacent or close to important breeding, feeding or nesting grounds for birds and bats[246].

5.2.3.5. Noise

- **Alternative operational modes** - Potential options for mitigating noise of wind turbines include sound-reduced operational modes and 'blade furniture', including various types of blade attachments such as trailing edge serrations, leading edge 'owl wing' serrations, stall strips or vortex generators[247].

- **Alternative turbine technology -** Variable speed and pitch regulated turbines (as opposed to fixed speed and stall regulated turbines) can reduce noise emissions as they can 'cut-in' more gently, while also maximising power generation[248, 249].

[244]See https://renewables-grid.eu/publications/press-releases/detail/news/launch-of-life-safelines4birds-project-to-reduce-mortality-of-birds-along-power-lines.html.

[245] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/457035.

[246] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/457035.

[247] Department for Business, Energy & Industrial Strategy. (2023). A review of noise guidance for onshore wind turbines. Available at https://www.wsp.com/en-gb/insights/wind-turbine-noise-report.

[248] See explanation on fixed vs variable speed and stall vs pitch regulated turbines here: https://www.wind-energy-the-facts.org/design-styles.html#:~:text=Stall%20control%20is%20a%20subtle,change%20to%20the%20rotor%20geometry.

[249] Department for Business, Energy & Industrial Strategy. (2023). A review of noise guidance for onshore wind turbines. Available at https://www.wsp.com/en-gb/insights/wind-turbine-noise-report.

5.2.4. Decommissioning stage

5.2.4.1. Collision

- **Scheduling of decommissioning activities** to avoid, reduce and/or phase activities during ecologically sensitive periods, following the same considerations that are applied in the construction phase.
- **Reducing the attraction factor to bats** as is done during the construction phase.

5.2.4.2. Habitat degradation

- **Managing and regulating contractor activity and movement**, including:
  - limiting work vehicles and machinery to designated areas only;
  - limiting natural vegetation clearance to the minimum necessary during decommissioning works;
- **Technical abatement measures** to minimise erosion and loss of vegetation, such as:
  - installing sufficient drainage works under all access roads, to reduce freshwater habitat fragmentation, avoid flooding land and damaging nearby waterbodies;
  - protecting existing vegetation through establishment of exclusion zones using fencing / barriers;
  - implementing soil erosion and sedimentation control measures.
- **Preventing the introduction and spread of invasive species** on the site, for example, by inspecting and washing all equipment and vehicles before they enter and leave the decommissioning site, managing storm and wastewater on site to avoid contamination and spreading of invasive species, using weed-free fill material, etc.

5.2.4.3. Noise

- **Alternative construction equipment** – Noise emissions may be reduced during infrastructure removal by choosing less noisy equipment, and by ensuring the use of well-maintained equipment and machinery[250].

[250] https://www.hsa.ie/eng/topics/physical_agents/noise/safe_maintenance_-_reducing_noise/.

5.3. Mitigation measures to avoid and minimise impacts of offshore wind

This section presents and discusses the application of mitigation measures to minimise the impacts of offshore wind projects according to the project phase.

Table 5-3 **Mitigation measures to avoid and minimise impacts of offshore wind** projects

Impact category	Impact	Mitigation measure	Type of measure	Planning	Construction	Operation	Decommission
Wildlife mortality and injury	Collision	Raise the height of the hub	Minimise – physical control				
		Paint the blade tips with bright colours	Minimise – physical control				
		Use of adaptive light controls	Minimise – physical control				
		Schedule construction activities to avoid ecologically sensitive periods	Avoid - scheduling				
		Restrict vessels' movement (M[251])	Minimise – operational control				
		Adjustment of lights	Minimise – physical control				
		Use of (audio, visual) deterrents	Minimise – physical control				
Habitat loss	Habitat loss and displacement of species	Define routes for vessels (M)	Minimise – operational control				
Ecosystem degradation	Noise	Selection of environmentally friendly materials	Avoid - design				
		Pile driving protocol	Minimise – operational control				
		Seasonal limitation of pile driving activities	Avoid- scheduling				
		Use of different types of foundations	Minimise – physical control				

[251] Measures that can be applied to mitigate multiple impacts are denoted with a letter M in parentheses.

Impact category	Impact	Mitigation measure	Type of measure	Planning	Construction	Operation	Decommission
		Soft start	Minimise – physical control				
		Adjust parameters of the pile stroke	Minimise – physical control				
		Use of sound barriers	Minimise – abatement control				
		Acoustic Deterrent Devices (ADDs)	Minimise – abatement control				
	Habitat degradation	Bury power lines	Avoid - design				
		Use of a fall pipe to release the dredged material	Minimise – physical control				
		Use of jet ploughing and horizontal direct drilling when installing cables	Minimise – physical control				
	Pollution	Management of waste disposal	Minimise – abatement control				
		Approval of chemicals, paints and coverings	Minimise – operational control				
		Check and maintenance of the vessels	Minimise – operational control				
		Survey of wind farm	Minimise – abatement control				
	EMF emission	Use protective material to cover the cables	Minimise – physical control				

5.3.1. Planning stage

5.3.1.1. Collision

The risk of birds colliding with wind turbines is one of the more significant environmental impacts associated with offshore wind development. Mitigation measures to reduce the risk of collision include:

- **Raising the height of the hub** and using larger and fewer turbines[252].

Box 12 – Reduced collision risks: example from the Belgian offshore wind farms

In 2022 an environmental impact assessment was conducted for an offshore wind farm to be built in the Belgian part of the North Sea[253]. The collision risk of the seabirds was assessed considering replacing the turbines with larger ones and increasing the hub height. The results showed an average 40% reduction of collision risk for 15 MW turbines, due to the higher distance between the lower tip of the rotor and the sea level as well as due to the fewer turbines per m^2. Additionally, by increasing the hub height of the turbines by a further 10 m, seabird collisions are expected to be reduced by on average 37% more.

- **Painting the blade tips with bright colours** can increase the visibility of the turbine and therefore reduce the possibility of collision with birds [254].

Box 13 – Innovative mitigation measure

An experimental project in the Eemshaven wind farm is conducting a trial to determine if painting only one of the turbine blades black will help reduce collision with birds. Results are expected in September 2024[255].

- Using **adaptive light controls** to manage light timing, intensity and colour. The use of lights with reduced or filtered blue, violet and ultra-violet wavelengths can also reduce the collision rates[256].
- **Restrictions on the vessels in the area** to reduce the risk of collisions with marine animals and turtles, which can be implemented by:
    - reducing the total number of vessels in the wind farm area as much as possible;
    - restricting movement of the vessels operating in the area to avoid sensitive areas such as roosting or feeding habitats for birds;
    - reducing the speed of vessels (which also mitigates the noise intensity)[257].

[252] Ibidem.
[253] Degraer, S., Brabant, R., Rumes, B. & Vigin, L. (eds). 2022. Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Getting ready for offshore wind farm expansion in the North Sea. Memoirs on the Marine Environment. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, 106 pp.
[254] Baltic Power (2022). Environmental impact assessment report for the Baltic power off-shore wind farm. Retrieved from: https://balticpower.pl/media/1171/environmental-impact-assessment-report-for-the-baltic-power-offshore-wind-farm.pdf.
[255] Caitlin Cunningham (2022) Mitigation and management across wind energy and other sectors Sustainable development in protected areas. https://www.europarc.org/wp-content/uploads/2023/07/ATS-report-Mitigation-and-management-across-wind-energy-and-other-sectors-Caitlin-Cunningham.pdf.
[256] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[257] Ibidem.

5.3.1.2. Habitat loss and displacement of species

- **Defining routes for vessels** in order to avoid sensitive birds and marine mammals' habitats[258]. Displacement effects can be significant for up to 9-12 km from the offshore wind areas[259].

5.3.1.3. Noise

- **Selection of materials, construction techniques and equipment** to be used in the wind project should aim at ensuring that the impact on the environment is as low as possible. For example, it is preferable to use foundations that do not require pile driving or drilling[260].

5.3.2. Construction phase

5.3.2.1. Collision

- **Scheduling of construction activities** to avoid, reduce and/or phase activities during ecologically sensitive periods, i.e., important/essential feeding, breeding, calving and/or migratory periods and diurnal or nocturnal movement patterns of species of concern, whereby:
  - The disturbance to the migratory birds can be avoided if construction activities are implemented outside the migration period[261];
  - Foundation installation schedules should consider marine mammal breeding and migratory periods, as well as fish spawning activity, avoiding construction works during this period[262].

5.3.2.2. Noise

Pile driving is considered as one of the most disturbing activities for the fish and the marine animals, which can also lead to lethal consequences. Several measures can be applied to mitigate this impact, which include:

- Establishing a pile driving **protocol** which includes considerations such as: the role, training and equipment of the marine mammal observer (MMO)[263]; the mitigation zone; the pre-pile driving search; delay if marine mammals are detected in the mitigation zone; soft-start pile driving procedures; breaks in pile driving activity; acoustic deterrent devices (ADDs); and reporting protocols[264].
  - The mitigation zone should have a radius of minimum 500 m but it can be adjusted and agreed with the relevant national authority, depending on the

[258] OSPAR. (n.d.). OSPAR Guidance on Environmental Considerations for Off-shore Wind Farm Development. Available at: https://www.vliz.be/imisdocs/publications/ocrd/224682.pdf.
[259] Garthe et al. (2023) Large-scale effects of offshore wind farms on seabirds of high conservation concern. https://www.nature.com/articles/s41598-023-31601-z.
[260] Ibidem.
[261] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[262] Ibidem.
[263] Marine Mammal Observer (MMO) is the individual responsible for the conducting visual watches for marine mammals. JNCC (2010) Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise). https://data.jncc.gov.uk/data/31662b6a-19ed-4918-9fab-8fbcff752046/JNCC-CNCB-Piling-protocol-August2010-Web.pdf.
[264] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.

species included in the area. If mammals are detected in the zone in the period of pre-pile driving research, the commencement of the pile driving should be delayed.

Box 14 – UK's pile driving protocol

The UK has established a protocol for the mitigation of underwater noise impacts from pile driving occurring during offshore farm construction activities. It is developed by Natural England together with the Countryside Council for Wales and the Joint Nature Conservation Committee (JNCC), which are the country's nature conservation bodies [265]. The aim of this protocol is to minimise the risk of injury or mortality to marine mammals near pile driving operations, rather than focusing on mitigating disturbance effects.

The pile driving protocol constitutes a segment of the general guidance "The protection of marine European Protected Species from injury and disturbance"[266], which was developed by the three conservation bodies and that is aimed at assisting marine developers, regulators, advisors and enforcement authorities in evaluating whether their activities are causing disturbance, injury or death of marine European Protected Species (EPS).

- **Seasonal limitation of pile driving activities** should be considered in periods of ecological importance, such as breeding or feeding seasons[267]. Some countries have already introduced such obligations, with the Netherlands allowing pilling between 1st of July and 31st of December, and Belgium between 2nd of May and 31st of December[268].
- **Physical and abatement controls** to reduce the noise from pile driving activities by:
    - Choosing **different types of foundations** e.g., gravity or floating foundations that do not require drilling[269];
    - Using **'soft-start'** when pilling, which refers to the gradual ramp up in hammer energy and blow frequency over 20 minutes or more[270];
    - **Adjusting the parameters of the pile stroke** (e.g., prolonging the impulse)[271];
    - Using **sound barriers** such as:
        - **Bubble curtains** (i.e., perforated hoses or pipes in a circle on the seabed around the pile driving site, produce ascending bubbles in the water, which deflect the propagated sound) [272];

[265] JNCC (2010) Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise. https://data.jncc.gov.uk/data/31662b6a-19ed-4918-9fab-8fbcff752046/JNCC-CNCB-Piling-protocol-August2010-Web.pdf.
[266] JNCC (2010) The protection of marine European Protected Species from injury and disturbance. https://assets.publishing.service.gov.uk/media/5dea1d35e5274a06dee23a34/Draft_Guidance_on_the_Protection_of_Marine_European_Protected_Species_from_Injurt_and_Disturbance.pdf.
[267] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/457035.
[268] European MSP Platform(2021) Conflict Fiche 8: Offshore wind and marine conservation. https://maritime-spatial-planning.ec.europa.eu/sites/default/files/sector/pdf/8_offshore_wind_conservation.pdf.
[269] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/457035.
[270] Ibidem.
[271] European MSP Platform(2021) Conflict Fiche 8: Offshore wind and marine conservation. https://maritime-spatial-planning.ec.europa.eu/sites/default/files/sector/pdf/8_offshore_wind_conservation.pdf.
[272] Ibidem.

  - **Shell-in-shell systems** (i.e., noise mitigation screens, consisting of a double-wall steel tube into which the pile is inserted. The gap between the walls is filled with air to deflect sound) [273];
  - **Hydro Sound Damper (HSD)**, (i.e., encircling the pile with HSD elements, which could be plastic foam elements or gas-filled balloons, aimed at deflecting or absorbing sound) [274].

- **Acoustic Deterrent Devices (ADDs)** can deter species from hazards such as fishing gear or commercial fish stocks. Some emit high intensity sounds to scare animals away, while others play recordings of distressed animals or their predators to discourage species from approaching ('scrammers', 'seal scarers', or 'pingers').
  - The pile driving protocol of JNCC provides some recommendations on the use of ADDs, such as using it in combination with visual and/or acoustic monitoring. However, the use of ADDs is relatively new, and has been tested in limited species such as harbour porpoise, grey seal and harbour seal[275].

Box 15 – Noise mitigation measures in Germany[276]

When an offshore wind farm gets approval by the authorities, the operators must prepare and submit a noise mitigation plan, addressing:

i) Utilisation of cutting-edge techniques for technical noise mitigation;
ii) Assessment of site and project specifics;
iii) Integration of findings from research and past projects.

The mitigation plan must be submitted six months prior to commencing construction. Furthermore, the following mitigation measures are considered standard procedures in Germany:

- Move harbour porpoise away from the area of works before pile driving; porpoises must remain 750m away from the construction area;
- Gradual increase of the noise intensity of the pile driving;
- Limitation of the noise level between 160 dB SEL (sound exposure level) to 190 dB Lpeak (peak level) within 750 m of the sound source;
- The effective time for driving a monopile to its target depth must not exceed 180 minutes, while for jacket piles, it is capped at 140 minutes per pile;
- Use of bubble curtain.

Finally, to limit disturbance, no more than 10% of the German North Sea area can be affected by pile driving noise from all wind farm projects at once. This is calculated by combining the impact areas of all projects under construction. However, during the May to August mating and breeding season, and in areas with high porpoise density, a stricter 1% limit is applied to protect harbour porpoises, especially in Special Areas of Conservation (SACs), where generally stricter regulations apply.

[273] Ibidem.
[274] Ibidem.
[275] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[276] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/457035.

5.3.2.3. Habitat degradation

- **Burying power lines (cables)** should take into account the location so that the impact on sensitive seabed environment and species is limited[277].
- The use of **scour protection should be limited** to cases where the structural integrity of the foundations is at risk[278], or nature-based design should be opted to enhance the biodiversity around the wind turbine structures[279,280].
- **Use of a fall pipe to release the dredged material** to the seabed enables a more accurate placement of material in the disposal zone and therefore can reduce the levels of suspended solids[281].
- When installing cables, **jet ploughing** is appropriate when the seabed is soft, while **horizontal direct drilling** has a lower impact when installing the export cable at landfall since it avoids the need for a cable trench[282].

5.3.2.4. Pollution

The pollution of the development area of offshore wind farms can be mitigated by adopting the following actions:

- **Management of waste disposal** and implementation of rapid management of any chemical leaks or spills protocol[283]. The waste disposal hierarchy should include avoidance, reduction, re-use, recycling, recovery, and residue disposal[284].
- **Prior approval** of all chemicals, paints and coverings as well as appropriate bunding of chemicals on land or vessels by the regulatory agencies that oversee the environmental protection and safety standards of each country (e.g., governmental bodies responsible for environmental regulation, occupational health and safety authorities, or maritime and shipping regulatory bodies)[285].
- Frequent **checking and maintenance of the vessels** to an appropriate standard and if applicable that they are certified to perform specific tasks[286].
- **Survey of the wind farm site** after the conclusion of the construction activities, to determine if any debris is identified on the seabed: if yes, it should be disposed of on land in accordance with proper waste management practices[287].

[277] Swedish Agency for Marine and Water Management. (2023). Coexistence of offshore wind power with commercial fishing, aquaculture and nature conservation. https://www.havochvatten.se/download/18.66b74fcf189fa80353f297a3/1692347346807/CoexistenceWithOff-shoreWind_EN.pdf.
[278] OSPAR. (n.d.). OSPAR Guidance on Environmental Considerations for Off-shore Wind Farm Development. Available at: https://www.vliz.be/imisdocs/publications/ocrd/224682.pdf.
[279] While this concept is relatively new, projects can be found in the US.
[280] The Nature Conservancy 2021) Turbine Reefs: Nature-Based Designs for Augmenting Offshore Wind Structures in the United States. https://www.nature.org/content/dam/tnc/nature/en/documents/TurbineReefs_Nature-BasedDesignsforOffshoreWind_FinalReport_Nov2021.pdf.
[281] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/457035.
[282] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[283] Ibidem.
[284] Ibidem.
[285] OSPAR. (n.d.). OSPAR Guidance on Environmental Considerations for Off-shore Wind Farm Development. Available at: https://www.vliz.be/imisdocs/publications/ocrd/224682.pdf.
[286] Ibidem.
[287] Ibidem.

5.3.2.5. EMF emission

- **Burying power lines** to reduce the magnitude of EMF emission into the seawater, either by burying lines at depths of 1 m and more, or covering the cable with protective material such as rock. However, some species might still be capable of detecting EMF even at deeper depths[288].

5.3.3. Operational stage

5.3.3.1. Collision

Reducing the risk of bird collision with the offshore wind turbines can be achieved by:

- **Adjustment of the lighting** either from steady red light to lights which flash or to the use of blue/green steady warning lights[289].
- **Use of deterrents** – devices installed on site that emit audible or visual signals continuously, periodically, or upon activation by a bird-detection system. Additionally, passive deterrents like painting can be used on turbine towers and blades[290].

<u>RAAs located near a major migratory route of birds</u>

- During mass-migration events, if the RAA is located near major migratory routes, **curtailment** should be used to reduce collision risk (especially in bad weather and visibility conditions), or rotating the rotor plane out of the direction of migration[291].
    - Data collected from the radars coupled with environmental inputs (e.g., weather forecast, seasonal considerations) should be used in models to predict the movement of birds especially during large-scale migration, and subsequently to initiate curtailment. Examples of applied forecast models for curtailment exist in Borssele and Egmond aan Zee wind farms (the Netherlands)[292].
    - Data collection can also be done by experienced bird field surveyors that are stationed at vantage points within and in the vicinity of the wind development area. If the observers identify a high risk of collision they notify the wind farm control centre to shut down the turbines[293].

Box 16 – Curtailment of offshore wind farms in the Netherlands[294]

In order to mitigate bat collisions, Dutch offshore wind farms are implementing the following measures in the period from 15th August to 30th September:

- The turbines have a cut-in at 5 m/s wind speed from one hour after sunset to two hours before sunrise;

[288] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/457035.
[289] Ibidem.
[290] European Commission, Directorate-General for Environment, Guidance document on wind energy developments and EU nature legislation, Publications Office of the European Union, 2020, https://data.europa.eu/doi/10.2779/457035.
[291] Ibidem.
[292] Ibidem.
[293] IUCN. (2021). Mitigating biodiversity impacts associated with solar and wind energy development – Guidelines for project developers. Retrieved from: https://doi.org/10.2305/IUCN.CH.2021.04.en.
[294] Ibidem.

- When the wind speed is less than this value, the number of rotations per minute per wind turbine should be less than one;
- The developers are obliged to report the implementation of this mitigation measure.

5.3.4. Decommissioning stage

5.3.4.1. Collision

- **Scheduling of decommissioning activities** to exclude the sensitive periods in case protected species remain in the area. For instance, in the Baltic Sea, decommissioning activities are preferable in the period between March to September when the birds' presence in the area is the lowest.

5.4. Mitigation measures to avoid and minimise impacts of solar power

This section presents and discusses the application of mitigation measures to minimise the impacts of solar power according to the project phase.

Table 5-4 Mitigation measures to avoid and minimise impacts of solar power projects

Impact category	Impact	Mitigation measure	Type of measure	Planning	Construction	Operation	Decommission
Wildlife mortality and injury	Collision, electrocution	Re-route, mark or bury powerlines (M[295])	Avoid - design				
		Design of transmission lines and pylons	Minimise – physical control				
		Attach bird flight diverters to transmission grounding wires	Minimise – physical control				
	Electrocution	Add insulation to power lines	Minimise – physical control				
	Disturbance of wildlife	Schedule construction activities to avoid ecologically sensitive periods	Avoid - scheduling				
		Buffer zones	Avoid - design				
	Attraction	Removal of soil heaps	Minimise – operational control				
		Use non-polarising white tape on PV panels	Minimise – physical control				
Habitat loss	Barrier effect	Micro-siting (M)	Avoid - design				
		Re-routing, marking or burying powerlines (M)	Avoid - design				
		Modifications to security fences	Minimise – physical control				
		Enhancement of boundary features to facilitate the movement of wildlife	Minimise – physical control				
Ecosystem degradation	Changes in microclimate	Consideration of type of solar PV panels	Avoid - design				
		Introducing vegetation below and around PV panels and reflection mirrors	Minimise – abatement control				

295 Measures that can be applied to mitigate multiple impacts are denoted with a letter M in parentheses.

Impact category	Impact	Mitigation measure	Type of measure	Planning	Construction	Operation	Decommission
	Habitat degradation	Minimising soil erosion and sedimentation	Minimise – physical control				
		Consideration of type of foundation	Minimise – physical control				
		Managing contractor activity and movement	Minimise – operational control				
		Minimise soil degradation by revegetation or planting agricultural crops	Minimise – physical control				
		Place vegetation under and around PV panels and reflection mirrors to reduce need for cleaning	Minimise – abatement control				

5.4.1. Planning stage

5.4.1.1. Wildlife mortality and injury

Wildlife can sustain serious injuries or death in contact with various elements of a solar power plant. Avoiding or reducing the risk of such disturbance to wildlife can be achieved by integrating some of the following measures in the planning stage of project development:

- **Buffer zones** can be established to minimise disturbance to at-risk species. An example of buffer zones can be found in Alberta (Canada) where recommended buffer areas range from 45 m to 1,000 m for solar plants to minimise impact on important wildlife habitats[296]. Specifically, the buffer zone of 1,000 m around a lake is the required legal standard to avoid the occurrence of a 'lake effect' for birds[297].
- **Design of transmission lines and pylons** to reduce risk of collision and electrocution, such as:
    - Reducing the number of vertical wire levels by adjusting the conductor heights to reduce the number of potential collision points;
    - Stringing wires as low as possible;
    - Keeping wire span lengths as short as possible to minimise line height as birds usually respond to seeing lines by increasing height; and
    - Using wires with a thicker diameter or bundling wires to increase visibility.
- **Re-routing of high voltage lines** should be considered to avoid or reduce the risk of electrocution and collision to birds and bats. This risk comes mainly from high voltage transmission lines used to export the power from the solar power plant to the transmission grid.
    - The high voltage lines should be re-routed to avoid sensitive areas if the RAA is located near areas such as bird migration routes and nesting sites near wetlands or waste sites[298].

5.4.1.2. Habitat loss and barrier effects

Barrier effects hinder the movement of animals and disrupt migration patterns. Construction of barriers such as fences causes the fragmentation and loss of habitats which leads to species isolation or displacement. During the planning phase of solar energy projects, measures can be taken to minimise barrier effects:

- Micro-siting and changing the layout of the infrastructure in the site can minimise barrier effects. Improving the layout of solar plants can be achieved by **clustering the solar arrays** in blocks with wildlife corridors between them[299]. To avoid barrier effect, literature suggests that the minimum module-to-ground distance should be at least 80 cm and the space between the module rows at least 3.5 m[300]. This measure has been implemented successfully in the Lieberose solar park in Germany, which is a large park built on a migratory route for red deer. To avoid and minimise barrier effect, the project site was divided into two separate sections to create a wildlife corridor[301].

[296] Ibidem.
[297] Urquhart, B. (2023). Where to Put a Solar Farm: The lesson of two proposed renewables projects—one accepted, one rejected. Retrieved from: https://albertaviews.ca/where-to-put-a-solar-farm/.
[298] IUCN (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Retrieved from: https://portals.iucn.org/library/node/49286.
[299] Ibidem.
[300] Stakeholder feedback to the survey.
[301] Renewable energies Agency (2010). Solar parks – Opportunities for Biodiversity. Renews Special (Issue 45). Retrieved from: https://www.unendlich-viel-energie.de/media/file/298.45_Renews_Special_Biodiv-in-Solarparks_EN.pdf.

- **Re-routing, marking or burying powerlines,** including those used for grid connection, can mitigate the barrier effect, in addition to reducing the risk of electrocution and collision (see under wildlife injury and mortality).
    - Re-routing entails the powerlines being placed outside the path of migratory corridors or other sensitive areas. This is especially relevant for RAAs that may be designated in proximity to migratory routes and sensitive areas, or in case they are located on an artificial and built surfaces within a Natura 2000 area (especially if the Natura 2000 site has been designated for bird and bat protection).
    - Marking includes the attachment of markers in the form of spirals, plates, flappers, swivels or spheres, which will increase visibility of installed infrastructure.
    - Burying means that the power cables are buried beneath the soil, thereby no longer forming an obstacle to wildlife. However, burying cables can potentially also have a negative impact on the ecosystem, so should be approached with caution, based on the ecosystem condition (e.g. in peatlands)[302].

[302] IUCN (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Retrieved from: https://portals.iucn.org/library/node/49286.

Box 17 – Mitigation measures when planning solar power – example from Germany

For the development of a solar plant in Salmdorf near Munich, various nature conservation measures were taken during the planning, construction and operation stages. The solar plant was built on a former agricultural field and was converted into an extensive grassland which improved the environmental quality considerably. The PV modules were built on an area of 1.1 hectares which used to be a gravel pit. For the construction on the prior agricultural site, this area was filled in with building rubble, material excavated during road construction, and then covered with a layer of topsoil. During construction of the solar park, a species-rich meadow was developed, covering the entire site of 6.7 hectares. This grassland is mown twice a year[303].

The mitigation and restoration measures introduced during the planning phase of this project (with execution happening during construction and operation phases in some cases) included the following:

- Avoidance of the use of foundations during the construction of the PV arrays to minimise soil sealing;
- Installing a chain-link fence to let small wild animals like hares, pheasants and partridges through while the solar plant is operational;
- Creation of a 4 to 8 metre wide belt of grassland with a border of hedges and trees to function as a buffer zone;
- A coppice at the northern end of the site serving as an ecological compensation area;
- Planting exclusively bushes at the southern, south-eastern and south-western edges;
- Planting of 4000 bushes and 30 trees on over 15 000 square metres of land;
- Construction of two ponds on the site to provide an attractive habitat for toad species at risk of extinction due to intensive building activities in the east of Munich ("green toad scheme") in cooperation with the city of Munich.

5.4.1.3. Changes in microclimate

Impacts of changes in microclimate are site specific, and their significance depends on the needs of the native habitats.

- One measure to mitigate these impacts is the selection of the most appropriate **type of solar PV panels** based on what conditions would favour native habitats. Solar PV fixed-mount system and tracking system affect microclimatic conditions differently:
  - Fixed-mount solar modules provide shade where the temperature is cooler and humidity is higher throughout the day;
  - Solar tracking systems create temporally varying shading conditions[304].

[303] Renewable energies Agency (2010). Solar parks – Opportunities for Biodiversity. Renews Special (Issue 45). Retrieved from: https://www.unendlich-viel-energie.de/media/file/298.45_Renews_Special_Biodiv-in-Solarparks_EN.pdf.
[304] OECD (2024). Mainstreaming Biodiversity into Renewable Power Infrastructure. Retrieved from: https://doi.org/10.1787/357ac474-en.

5.4.2. Construction stage

5.4.2.1. Wildlife mortality and injury

There are certain periods of year in which wildlife is more vulnerable to impacts of human activities (e.g., noise, increased movement in a habitat). This sensitivity should be taken into consideration and adequate measures planned to reduce impacts on species.

- **Scheduling construction activities** to avoid disturbing native species during sensitive periods can reduce negative impacts. The timing of construction works should be adapted to consider seasonal periods of importance for feeding, breeding and migration as well as diurnal/nocturnal activity and movement patterns.
    - A specific example involves small non-volant species, such as reptiles and amphibians, which are particularly vulnerable during breeding or hibernation periods. In these periods they can be concentrated in specific habitats with limited mobility, due to their breeding or juvenile state. As such, these specific areas should be avoided during the breeding season[305].
- **Removing any soil heaps** immediately during construction will reduce the risk of wildlife creating refuge in them[306]. Namely, during construction a risk exists that due to the excavation of soil, new attractive habitats are created, attracting insects and smaller animals to nest. If this is allowed, this wildlife may be injured or killed at a later stage, when soil heaps are removed.

5.4.2.2. Habitat degradation

Reducing impact of construction activities on the quality and integrity of habitat can be achieved through the following measures:

- **Technical abatement measures** to minimise soil erosion and sedimentation, such as:
    - Installing erosion control blankets which keep the soil in place during heavy rains and winds;
    - Sowing seeds to stimulate vegetation growth (through hydro- or dry sowing) and layering mulch or geotextiles over the topsoil to reduce runoff and keep the soil in place[307];
    - Limiting vegetation clearance to the minimum and using manual methods (e.g. hoeing or hand-pulling) where possible to limit soil disturbance;
    - Creating drainage infrastructure under all access roads in order to minimise freshwater habitat fragmentation to avoid flooding land and damaging nearby waterbodies.[308]
- **Mounting solar panels on pile-driven or screw-on foundations** (e.g. support spikes)[309] to prevent or minimise soil sealing caused by heavy foundations used to anchor the solar panels in the ground (e.g., trench-fill or mass concrete foundations). This disturbs soil functions such as filtering and buffering.
- **Managing and regulating contractor activity and movement** while on construction site, including:
    - Locating the temporary construction facilities away from sensitive areas by designating construction and access areas on existing infrastructure and roads,

[305] IUCN (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Retrieved from: https://portals.iucn.org/library/node/49286.
[306] Ibidem.
[307] Folk, E. (2020). How renewable energy professionals can reduce erosion. Retrieved from: https://greencleanguide.com/how-renewable-energy-professionals-can-reduce-erosion/.
[308] IUCN (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Retrieved from: https://portals.iucn.org/library/node/49286.
[309] Ibidem.

meaning that work vehicles, storage areas and machinery will be grouped and stored in specific designated low-risk areas;
  - Limiting the number and speed of vehicle movements to, from and within the site, which is particularly relevant during the wet or winter periods;
  - Prohibiting travel on unauthorised roads to protect existing vegetation and minimise soil inversion, as well as venturing in any protected or sensitive areas that may be in the vicinity[310].

Box 18 – Restoration

Despite best efforts in trying to avoid or minimise construction impacts related to habitat degradation, some environmental damage is inevitable. **Restoration** should be undertaken to reinstate the habitat to its original conditions and functions. Some best practices include:[311]

- Revegetating temporary-use and lay down areas as soon as reasonably practicable after construction activities are complete;
- Separately retaining and storing topsoil and sub-soil stripped from the construction areas for later use during reinstatement;
- Using indigenous and non-invasive species for landscaping and rehabilitation works; and
- Using soil, mulch and vegetation debris (that contain natural seed stock) to facilitate natural revegetation of disturbed areas, where reasonably practicable.
- Ideally, restoration will be implemented in a phased approach in the project site: when construction work on one area of the site has concluded, restoration work is undertaken at the same time as the start of construction on a different area of the site.

5.4.3. Operational stage

5.4.3.1. Wildlife mortality and injury

During operation of a solar energy plant, there are various impacts that can lead to injury or death of wildlife. Mitigating these impacts can be done, as follows:

- Attraction - Reflection effects of PV panels that attract aquatic insects, which perceive it as the reflective surfaces of waterbodies, can be decreased by using **non-polarising white tape** around and across panels to create white borders and grid patterns[312].
- Collision – measures can minimise the collision risk for birds and bats include: Attaching **bird flight diverters** (e.g. flappers, balls or spirals) to transmission grounding wires to increase their visibility[313].

[310] Ibidem.
[311] Ibidem.
[312] European Commission (2020). Potential impacts of solar, geothermal and ocean energy on habitats and species protected under the habitats and birds directives – Final report. Retrieved from: https://data.europa.eu/doi/10.2779/784768.
[313] IUCN (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Retrieved from: https://portals.iucn.org/library/node/49293.

- Electrocution – **Changing the design** of low- or medium-voltage powerlines by adding insulation, to reduce the risk of electrocution of birds[314].

5.4.3.2. Habitat loss and barrier effects

To mitigate barrier effects during the operation of a solar energy plant, the following measures can be implemented to facilitate the movement of animals:

- **Modifications to security fences** such as:
  - creating a gap between the base of the fence and the ground (ideally of 10-15 cm) either at regular intervals or along the whole fence;
  - installing permeable fencing in the form of hedges or ditches, fences with regular passages (e.g. culverts) or fences with larger mesh sizes to allow for (small) animal movement.
- **Enhancing existing boundary features** to connect the solar power site to features in the wider landscape, through, for example, installing hedgerows, ditches, stone walls, hedge banks, field margins and scrub. These boundary features can function as wildlife corridors, sheltering areas, nesting grounds and foraging areas[315].

5.4.3.3. Habitat degradation

- **Revegetation and planting agricultural crops** under and around PV arrays can minimise soil degradation on the site. It reduces the desertification process of the surrounding area, as it increases vegetation cover, reduces dust emissions and improves the water retention capacity of the soil[316].

Box 19 – Extensive site management: Grazing as site maintenance in Germany

At the Fürth-Atzenhof solar park, in Germany, the grassland which was installed under and around the PV arrays is maintained through less intrusive ways by employing a shepherd. Instead of using biocides or herbicides, the shepherd lets sheep graze twice a year. This ensured that shrubs and trees did not appear all over the site, possibly damaging or shading PV panels (thus interfering with the electricity generation). The 1-hectare solar plant was built in 2003 on the southern slope of the former municipal landfill site. Research conducted in 2009 revealed the presence of a wide diversity of plant species. In total 254 types of ferns and flowering plants and 30 types of moss were found. 23 of the species found on the site are included on endangered lists at regional, national or international level, showing the positive impact of natural site maintenance on conserving and even increasing biodiversity[317].

5.4.3.4. Changes in the microclimate

The changes in microclimate caused by the PV panels can be mitigated by:

- **Introducing vegetation**, which will reduce the surface temperature of the soil under and around the solar energy plant elements.

[314] European Commission (2020). Potential impacts of solar, geothermal and ocean energy on habitats and species protected under the habitats and birds directives – Final report. Retrieved from: https://data.europa.eu/doi/10.2779/784768
[315] European Commission (2020). Potential impacts of solar, geothermal and ocean energy on habitats and species protected under the habitats and birds directives – Final report. Retrieved from: https://data.europa.eu/doi/10.2779/784761
[316] Thomas, S., Thomas, S., Sahoo, S., Kumar, A., & Awad, M. (2023). Solar parks: A review on impacts, mitigation mechanism through agrivoltaics and techno-economic analysis. Energy Nexus, 11, 100220. Retrieved from: https://www.sciencedirect.com/science/article/pii/S2772427123000505
[317] Renewable energies Agency (2010). Solar parks – Opportunities for Biodiversity. Renews Special (Issue 45). Retrieved from: https://www.unendlich-viel-energie.de/media/file/298.45_Renews_Special_Biodiv-in-Solarparks_EN.pdf

    - A study in Malaysia showed that growing spinach and aloe vera between ground-mounted solar panels led to a temperature reduction of 0.85%, while increasing annual electricity yield by 2.8%[318]. However, a sufficiently large spacing between PV modules and arrays is necessary for adequate vegetation growth.
- **Passive cooling techniques** to avoid overheating of PV arrays[319].
    - Some examples of these techniques are immersion cooling, heat pipes, natural air cooling with fins, heat sinks, and improved heat exchanger designs[320].

5.4.4. Decommissioning stage

5.4.4.1. Wildlife mortality and injury

- **Scheduling of decommissioning activities** to avoid disturbance of wildlife during sensitive periods is the key measure to minimise wildlife injury and death during decommissioning. This includes taking into account:
    - Seasonal cycles such as critical breeding and migratory periods of species at risk;
    - Diurnal or nocturnal movement patterns of species at risk;
    - Seasonality in the wider ecosystem (e.g., seasonal tree fruiting or forage availability), or the presence of temporary wetlands, which may influence the behaviour of species[321].

5.4.4.2. Habitat degradation

Habitat degradation can be minimised through following:

- **Managing and regulating contractor activity and movement** while on construction site, including:
    - Locating the temporary construction facilities away from sensitive areas by designating construction and access areas on existing infrastructure and roads, meaning that work vehicles, storage areas and machinery will be grouped and stored in specific designated low-risk areas;
    - Limiting the number and speed of vehicle movements to, from and within the site, which is particularly relevant during the wet or winter periods;
    - Prohibiting travel on unauthorised roads to protect existing vegetation and minimise soil inversion, as well as venturing in any protected or sensitive areas that may be in the vicinity[322].

[318] Thomas, S., Thomas, S., Sahoo, S., Kumar, A., & Awad, M. (2023). Solar parks: A review on impacts, mitigation mechanism through agrivoltaics and techno-economic analysis. Energy Nexus, 11, 100220. Retrieved from: https://www.sciencedirect.com/science/article/pii/S2772427123000505.

[319] IUCN (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Retrieved from: https://portals.iucn.org/library/node/49283.

[320] Sharaf, M., Yousef, M., & Huzayyin, A. (2022). Review of cooling techniques used to enhance the efficiency of photovoltaic power systems. Environmental Science and Pollution Research, *29,* 26131-26159. Retrieved from: https://link.springer.com/article/10.1007/s11356-022-18719-9#:~:text=Discussion,most%20of%20the%20PV%20installations.

[321] IUCN (2021). Mitigating biodiversity impacts associated with solar and wind energy development. Retrieved from: https://portals.iucn.org/library/node/49283.

[322] Ibidem.

Annex A – List of sources analysed

Literature resources used for identifying environmental impacts and mitigation measures for onshore wind energy

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