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Mitigating biodiversity impacts associated with solar and wind energy development

Guidelines for project developers



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About The Biodiversity Consultancy

The Biodiversity Consultancy is a specialist consultancy in biodiversity risk management. We work with sector-leading clients to integrate nature into business decision-making and design practical environmental solutions that deliver nature-positive outcomes. We provide technical and policy expertise to manage biodiversity impacts at a project level and enable purpose-driven companies to create on-the-ground opportunities to regenerate our natural environment.

As strategic advisor to some of the world's largest companies, we lead the development of post-2020 corporate strategies, biodiversity metrics, science-based targets, and sustainable supply chains. Our expertise is applied across the renewable energy sector, including hydropower, solar, wind, and geothermal, where we specialise in the interpretation and application of international finance safeguards.

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Foreword

Today, our planet faces the interconnected, existential threats of climate change and biodiversity loss. Human activities, especially burning fossil fuels and deforestation, have disrupted the Earth's climate system. Concurrently, biodiversity loss has reached unprecedented rates with three-quarters of land surface now severely altered by human activity and one million species threatened with extinction. These two crises are deeply interlinked: climate change is a significant driver of biodiversity loss, and the loss of biodiversity exacerbates the climate crisis.

To limit global warming to 1.5°C and avoid the most catastrophic effects of climate change, humanity's carbon dioxide (CO_2) emissions must reach net-zero by 2050. Using renewable energy is one of the most effective and readily available ways of reducing CO_2 emissions. A combination of renewable energy, mostly from wind and photovoltaic solar, with more electrification to substitute fossil fuel use, could deliver three-quarters of the required energy-related emissions reductions. If poorly managed, however, the expansion of renewable energy may cause additional loss of biodiversity and disruption of the ecosystem services on which we all depend. Solar and wind energy developments, for example, often involve the destruction or fragmentation of wildlife habitat, and the extraction of the raw materials needed for renewable energy technologies carry substantive biodiversity risks.

A transition to renewable energy which both avoids harm and contributes to nature conservation is therefore essential, but can only happen with the support of all relevant decision makers at every stage of planning and implementation. Governments need to ensure risks to nature are identified as early as possible and take action to mitigate them, such as protecting undisturbed areas from developments. Financial institutions can attach similar safeguards to loans and investments, and energy companies should avoid, minimise, restore and then offset the remaining impacts on biodiversity throughout the lifecycle of all projects.

If we are to achieve net-zero emissions through renewable energy sources, we also need new energy technologies to make energy consumption more efficient, and to integrate circular economic principles. Furthermore, recognising that energy is a basic human right and integral to alleviating poverty calls for the provision of 'clean' electricity to all people across the world. Any increase in the supply of renewable energy must be matched by investment to guarantee reliable and widespread access to it, and a transition away from fossil fuel production and subsidies.

The picture is complex, and reaching our sustainable energy and biodiversity goals requires action from us all. In these guidelines, we aim to define practical, evidence-based measures to mitigate the impacts on biodiversity associated with solar and wind projects. We hope they will stimulate discussion, and help ensure that both the nature and climate crises are addressed collaboratively. It has become increasingly clear that investment in renewable energy is critical, but to be successful any transition to a net-zero carbon energy model must also protect nature. We welcome others to join us on this mission.

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Executive summary

Achieving a climate-resilient future, in accordance with the Paris Agreement and the Sustainable Development Goals (SDGs), requires rapid, sustained and far-reaching transformations in energy, land-use, infrastructure and industrial systems. Large-scale expansion of renewable energy can play a critical role in meeting the world's growing energy demands and in the fight against climate change. However, even 'clean' energy sources can have significant unintended impacts on the environment. A truly sustainable green energy transition must therefore be carefully planned and managed so that it does not come at an unacceptable cost to nature.

To manage risks, wind and solar expansion must account for biodiversity at national or regional scales. Strategic-level planning and early identification of risks through screening are effective tools to avoid placing developments in areas of high sensitivity for biodiversity. Developments away from such areas are much more likely to avoid significant biodiversity risks, meet regulatory requirements and align with lender standards and stakeholder expectations.

Poorly sited projects, together with associated infrastructure such as access roads and powerlines, can lead to significant loss of natural habitat from the footprint area. A large concentration of wind or solar farms in combination with other developments can increase habitat fragmentation, create barriers for species movement and potentially cause significant cumulative impacts to species' populations. The water demands of solar plants can put strain on local water resources and create ecological change. Of particular concern are developments that are placed in or near to areas recognised for their conservation significance, including sensitive breeding areas, important species migration routes, Key Biodiversity Areas and protected areas. Developments that are incompatible with the objectives or the conservation outcomes of a protected or conserved area must be avoided.

Wind and solar projects can impact species directly. Some birds are at risk from collision with wind turbines or with associated transmission lines, potentially leading to high fatality rates across a wide range of vulnerable species groups including vultures, bustards, cranes and many migratory species. Electrocution due to poorly designed low- and medium-voltage lines continues to pose a significant risk to many birds, particularly threatened raptors.

Bats also face collision risk, although the response of bats to turbines differs widely across species and locations. Studies from the northern temperate zone indicate a large variety of bats are at risk, especially species adapted for foraging insects in open spaces. Without appropriate mitigation in place, turbine collisions can lead to significant declines of local bat populations.

In addition to birds and bats, species vulnerable to offshore wind developments include marine mammals, particularly when exposed to high noise during construction, sea turtles and some fish species. Mammals and sea turtles face risks of collision with associated vessels, while habitat alteration can affect species of the seafloor.

The mitigation hierarchy provides developers with an effective framework to address risks through the sequential and iterative application of four actions: avoid, minimise, restore and (if necessary) offset. Effective application focuses on early avoidance and minimisation through project planning and design, including identification of site alternatives, design modifications and continual evaluation and improvement. Project repowering also provides opportunities to address unforeseen impacts and implement new and effective mitigation measures.

Avoidance measures that are effective during project design include burying power lines or routing them to avoid sensitive areas such as wetlands or bird migration corridors. Infrastructure micro-siting options include adapting the configuration of turbines to reduce risk of collision and barriers to species movement. Marking transmission lines with bird diverters is now standard good practice and has been shown to significantly reduce the numbers of collisions. Risk of bird electrocution can be almost eliminated through construction of safe distribution lines that include insulation and spacing of conductors. Such measures are often straightforward and cost-effective to integrate into design.

Effective avoidance and minimisation during project construction often require a good understanding of species behaviour, for example to avoid construction during sensitive breeding and migratory periods. For offshore developments, noise impacts can be minimised by implementing strict construction protocols that include acoustic monitoring, soft starts and acoustic deterrent devices.

New mitigation approaches and technologies offer opportunities to minimise risks while operating wind and solar projects. These include procedures to shut down specific turbines based on real-time observations of bird activity in the area using either field observers, image-based detection and/or radar technology. Measures to reduce collisions by making turbine blades more visible to birds are showing promising results but require further field testing. For bats, stopping turbine blades from operating during low wind speeds provides a proven strategy to reduce collision risk at a minimal cost to energy generation. Acoustic deterrents may also be effective for some species.

Careful siting through early project planning combined with on-site mitigation can often eliminate the need for biodiversity offsets. However, offsets may be required where projects have unanticipated impacts, or predicted impacts that cannot be fully addressed. Offsets for wind and solar developments can bring particular challenges, including accurately predicting residual impacts, particularly in data-poor areas where the technologies may be new. For migratory birds, the most effective interventions may be at breeding or wintering grounds that are far from the project site, making it challenging to secure offsets and gain support from local project stakeholders.

Where significant residual impacts are unavoidable, offsets should be planned and implemented based on best practice principles to ensure that they achieve demonstrable gains, do not negatively affect people and, ideally, contribute towards wider national or regional conservation goals. One way for developers to address cumulative impacts to similar biodiversity is to channel resources into a single, aggregated offset. Aggregated offsets have the benefit of increasing the likelihood of success whilst spreading risks and costs across several developers.

Beyond actions that aim to deliver measurable no net loss or net gain targets, there is often potential for proactive conservation actions to contribute to local conservation efforts and help deliver positive outcomes for people and nature. Onshore wind and

solar farms offer opportunities to restore and enhance habitats in previously degraded areas whilst artificial reefs protecting the foundations of offshore turbines can enhance biodiversity and fish stocks.

The recent rapid upscaling of wind and solar development means our understanding of the biodiversity impacts is often lagging. Considerable information gaps remain, both across technology types and species groups, and for both impacts and the effectiveness of mitigation. For example, the ability to predict collision risk is more advanced for birds than bats, while there is comparatively little knowledge on population-level impacts for either groups. Most estimates of seabird collision are based on theory rather than empirical evidence, because of the difficulties of monitoring fatalities offshore.

Most research and experience comes from North America and Europe, where wind and solar developments are relatively well established. Information gaps are particularly prevalent in many regions with ambitious renewable energy expansion plans, including global biodiversity hotspots in the tropics. Further testing and ongoing data collection is needed to help identify sensitive areas and improve the evidence base for emerging mitigation approaches. Standardised monitoring protocols, data sharing and transparency can all help assess cumulative impacts and support development of strategic landscape/seascape-level planning that accounts for biodiversity.

Emerging technologies such as floating solar and floating wind are gathering pace and allowing renewable energy development in previously inaccessible areas, such as deeper offshore waters. Floating wind turbines may have a lower footprint than fixed ones, but carry their own specific risks, including altering of local ecological conditions and the potential for entanglement of marine mammals with anchor cables. Further research is needed to understand the particular risks associated with these new technologies and develop effective strategies to manage them.

Mining of materials needed for renewable energy development can themselves have significant impacts where they are sourced from natural habitats. Without strategic planning, such biodiversity impacts risk outweighing the biodiversity benefits of climate mitigation from renewable energy. Businesses are increasingly expected to account for the impacts along their supply chain. In addition to sustainable sourcing of materials, optimising their reuse is an important strategy within the renewable sector to reduce the need for raw materials.

About these guidelines

Purpose and scope

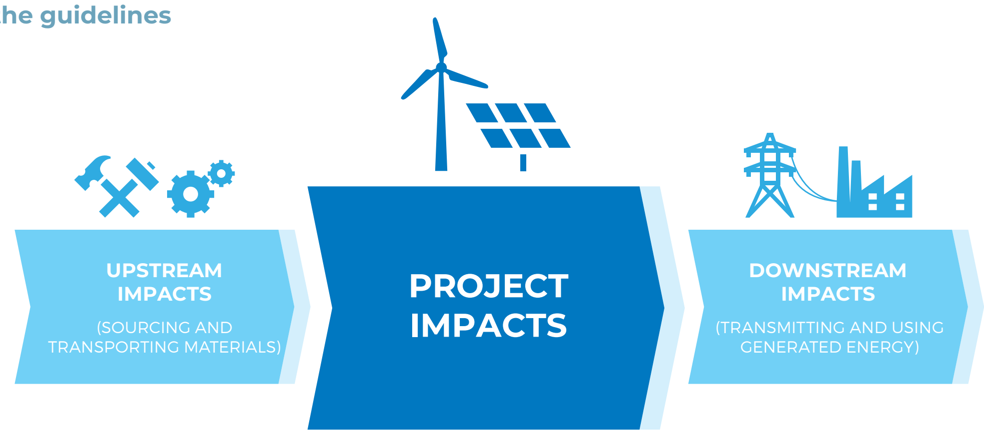
The guidelines aim to provide practical support for solar and wind energy developments by effectively managing risks and improving overall outcomes related to biodiversity and ecosystem services. They are industry-focused and can be applied across the whole project development life cycle, from early planning through to decommissioning and repowering, using the mitigation hierarchy as a clear framework for planning and implementation.[1] The mitigation hierarchy is applied to direct, indirect and cumulative impacts. Supply chain impacts are briefly presented in Section 10, but are not the focus of these guidelines.

The specific objectives of the guidelines are to:

- Serve as an integrated and practical reference source that presents good practice approaches to manage impacts on biodiversity and ecosystem services;
- Highlight the importance of avoiding impact through project siting, and the role of wider spatial planning in underpinning this;
- Bring together knowledge derived from industry experience, experts in relevant fields and the current scientific literature, while recognising the knowledge gaps relating to both impacts and the effectiveness of mitigation measures; and
- Consolidate information on existing resources relevant to good practice, where readers can find additional detailed information (Annex 1).

The guidelines focus on the needs of businesses in the solar and wind energy sectors, including project developers, investors and operators. The information will also be relevant to government planners in the energy and power sector, and other government agencies and non-governmental organisations (NGOs) working in nature conservation. The guidelines can also be used by governments to help develop national permitting requirements, EIA processes and appropriate spatial planning exercises, as well as setting national conservation targets and commitments under international agreements.

Scope of the guidelines



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1 Wind and solar technologies, such as floating photovoltaic and bladeless wind turbines, are evolving rapidly. While the guidelines do not specifically address such emerging technologies, the same mitigation principles and approaches are broadly applicable.

There is an extensive scientific literature on solar and wind energy in relation to biodiversity, and some guidance documents already exist. These guidelines draw on these materials to present a synthesis that is as far as possible up to date, evidence-based and organised in a way that is practical, concise and project-focused. Where relevant, the guidance signposts other documents where issues can be explored in more detail.

The recent rapid upscaling of wind and solar development means that our understanding of the biodiversity impacts often lags behind. Considerable information gaps and issues of data paucity remain that require urgent attention. Further, effective and practical mitigation solutions that can be applied across regions and species taxa may not yet be available or remain unproven. A particular concern is that, although wind and solar energy is rapidly expanding in the tropics and sub-tropics, most experience and research to date is derived from North America and Europe: there are large knowledge gaps for other parts of the world.[2] Readers are encouraged to share information and experiences on impacts and mitigation effectiveness, to help contribute to improving the knowledge base for solar and wind sectors in the longer term.[3]

How to use these guidelines

Section 1 provides an overview of the expected transformation in the energy sector due to the growth in renewable energy sources, the potential implications for biodiversity and ecosystem services and an introduction to the guidelines.

Section 2 introduces and explains the mitigation hierarchy, which provides the overall framework for presenting good practice approaches to managing the impacts of wind and solar developments on biodiversity and ecosystem services.

Section 3 explains the importance of early project planning, and the tools and approaches that can be used to inform the first step (avoidance) of the mitigation hierarchy. This applies to all solar and wind technologies.

Section 4, Section 5 and Section 6 examine potential impacts and mitigation approaches for each of the technology types: solar (both PV and CSP), onshore wind and offshore wind.

Section 7, Section 8, Section 9 and Section 10 cover issues that are general to all the technology types. Section 7 specifically outlines the principles and practical considerations for designing and implementing offsets that compensate for residual project impacts (after rigorous application of avoidance, minimisation and restoration in project design).

Section 8 explains considerations and good practice approaches for assessment, monitoring and adaptive management, and signposts more detailed guidance relevant to specific technologies.

Section 9 provides a summary of key project outputs required for aligning with good biodiversity management throughout the project lifecycle, including for the Environmental and Social Impacts Assessment (ESIA), and key additional sources of guidance and information for each of these. Although the scope of the guidelines is global, specific project conditions and requirements (from permitting authorities or financers) can vary between locations. Of particular relevance are the requirements for undertaking ESIAs, which vary by country. Hence, this guidance document should be interpreted with reference to the local environmental, social and legislative context. Specialist input and advice will be needed to understand and effectively manage biodiversity and ecosystem services risks related to each development.

2 See Jones et al. (2015) for a map highlighting studies on wind impacts per country.
3 See, for example, Conservation Evidence, a database and scientific journal.

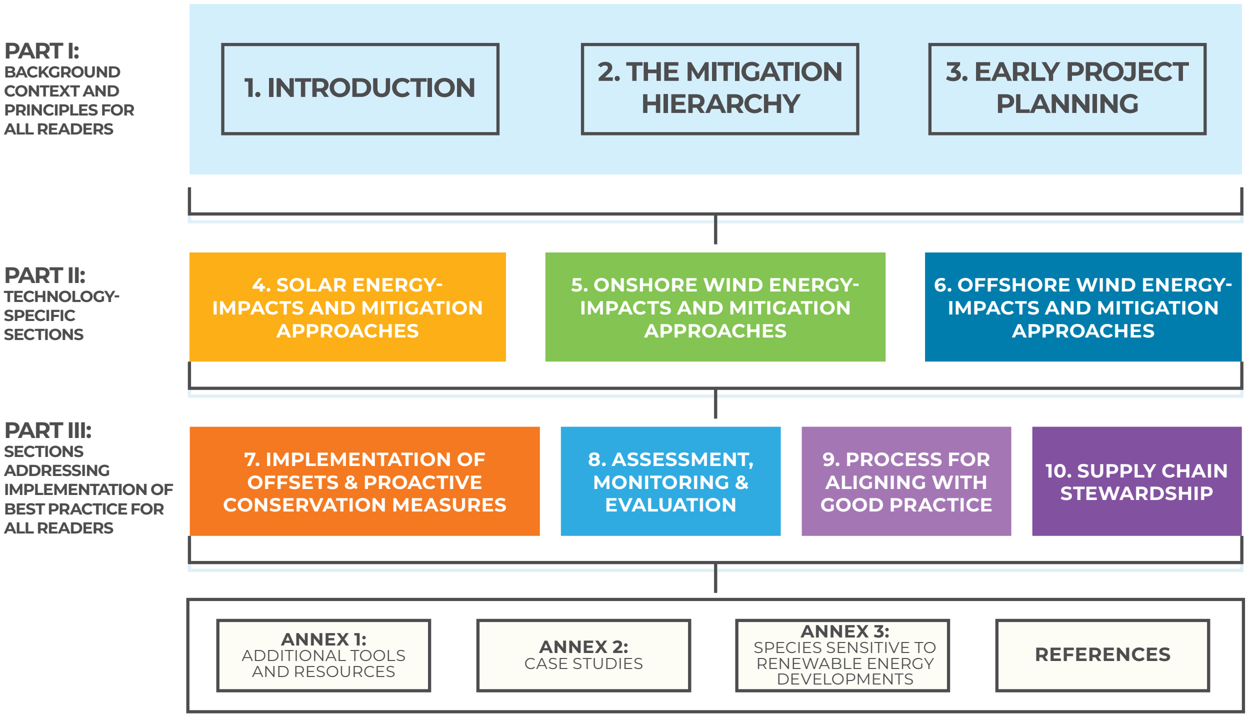
Section 10 reviews the issue of supply chain stewardship, and how projects can reduce the embedded impacts of materials.

A database with additional tools and resources to supplement information presented in each section is provided in Annex 1. This resource will be updated based on the latest evidence and information.

Annex 2 presents 33 case studies to help illustrate the main points and highlight suitable mitigation approaches.

Finally, Annex 3 provides a list of species groups that are known to be particularly sensitive to solar and wind developments.

Structure of the guidelines



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Glossary

Definitions presented here are intended to clarify the terminology used within these guidelines. Biodiversity-related terms draw mainly from The Biodiversity Consultancy (TBC) (2015), UNEP-WCMC's Biodiversity a-z and the BBOP Glossary.

Avoidance	Measures taken to anticipate and prevent adverse impacts on biodiversity before actions or decisions are taken that could lead to such impacts (TBC, 2015).
Area of Influence	The area affected by a project and its activities, including as a result of its direct, indirect and cumulative impacts. The area of influence also needs to account for the impacts of a project's associated facilities (i.e. those external activities or facilities necessary to conduct the project and that exist primarily to support the project).
Biodiversity	'Biological diversity' means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems (Biodiversity a-z).
Benthic	Living on or under the sediments or other substrate (Biodiversity a-z).
Blade feathering	Changing the pitch angle of all the main rotor blades to prevent or slow the rotation of the blades when it is idling.
Critical habitat	Areas of high biodiversity conservation significance based on the existence of habitat of significant importance to critically endangered or endangered species, endemic and/or range-restricted species, highly threatened and/or unique ecosystems and key evolutionary processes, as well as globally significant concentrations of migratory and/or congregatory species (IFC, 2012). Critical habitat is also a term used in the U.S. Endangered Species Act, referring to specific geographic areas that contain features essential to the conservation of an endangered or threatened species and that may require special management and protection. Critical habitat may also include areas that are not currently occupied by the species but will be needed for its recovery.
Conserved areas	Conserved areas include a wide range of sites that deliver effective conservation outcomes, but where the area may have been established for other reasons. Included in this broad range of conserved areas are "other effective area-based conservation measures" (OECMs) (see also OECM definition below).
Constraints mapping	The process of mapping an area based on technical, environmental, and social sensitivities. Used to identify potential development opportunities and conflicts within the landscape or seascape. See also sensitivity mapping.
Cumulative impacts	Total impacts resulting from the successive, incremental, and/or combined effects of a project when added to other existing, planned and/or reasonably anticipated future projects, as well as background pressures (IFC, 2012).
Cut-in speed	The speed at which the turbine first starts to rotate and generate power.
Decommissioning	The process involving the planning of and implementing the removal, disposal, or reuse of an installation when it is no longer needed for its current purpose.
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (Biodiversity a-z).

Ecosystem services	Benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services, such as recreational, spiritual, religious and other non-material benefits (BBOP, 2012).
Electrification	The process of powering using electricity.
End-of-life extension	The process by which operating life is extended beyond the original plan and license.
Free, prior and informed consent (FPIC)	Free, prior and informed consent (FPIC) is the right of a party with legitimate rights to their lands, territories and resources to freely grant authorisation to another party, within existing legal frameworks (including customary law), for the execution of certain activity that implies access to, and use of, tangible or intangible resources of the party granting authorisation, or that may affect such lands, territories and resources (IUCN ESMS Manual). This right specifically pertains to indigenous peoples and is recognised in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP).
Habitat	The place or type of site where an organism or population naturally occurs (Biodiversity a-z).
Habitat fragmentation	Splitting continuous habitat into distinct pieces (Biodiversity a-z).
Impact	Impacts to biodiversity are changes to any components of biodiversity, including genes, species or ecosystems, whether adverse or beneficial, wholly or partially resulting from a project's actions. This can in turn lead to a breakdown in the functioning of the ecosystem and the ecosystem services it provides to people.
Indirect impacts	Indirect impacts (sometimes called secondary impacts or induced impacts), are impacts triggered in response to the presence of the project, rather than being directly caused by the project's own operations. For instance, the presence of a project may lead to an increased local workforce and associated increases in demand for food. This may have knock-on effects on biodiversity, for example due to increased land conversion for farming or increased levels of hunting. Indirect impacts may reach outside project boundaries and may begin before or extend beyond a project's lifecycle. As a general rule, indirect impacts are more difficult to map and quantify than direct impacts (BBOP, 2012).
International Finance Institution (IFI)	A financial institution chartered/established by more than one country, and hence subject to international law. Multilateral Development Banks (MDBs) are a type of IFI created by two or more countries for the purpose of encouraging economic development in poorer nations.
Key Biodiversity Area (KBA)	Sites recognised globally as contributing significantly to the global persistence of biodiversity (IUCN, 2016).
Micro-siting	The placement, design and layout of the facility within the project site.
Migratory soaring birds	Migratory species are those in which a significant proportion of the population, or geographically separate parts of the population, cyclically move from one seasonal range to another. This includes many soaring birds, which are those bird species that can maintain flight without flapping, rising on wind currents.
Minimisation	Measures taken to reduce the duration, intensity, significance and/or extent of impacts (including direct, indirect and cumulative impacts, as appropriate) that cannot be completely avoided, as far as is practically feasible (TBC, 2015).
Mitigation hierarchy	A framework for managing risks and potential impacts related to biodiversity and ecosystem services. These Guidelines follow the definition of the mitigation hierarchy, which is: "the sequence of actions to anticipate and avoid, and where avoidance is not possible, to minimise and, when impacts occur, to restore, and where significant residual impacts remain, offset" (TBC, 2015).

Modified Habitat	Areas in which a large proportion of species are of non-native origin, and/or where human activity has substantially modified an area's primary ecological functions and species composition prior to the onset of a project (IFC, 2012).
Multilateral Development Bank (MDB)	See International Finance Institution (IFI).
Natural Habitat	Areas composed of viable assemblages of plant and/or animal species of largely native origin, and/or where human activity has not essentially modified an area's primary ecological functions and species composition IFC (2012).
Net gain	The point at which project-related impacts on biodiversity and ecosystem services are outweighed by measures taken according to the mitigation hierarchy, resulting in a net gain. May also be referred to as net positive impact (TBC, 2015).
No Net Loss	The point at which project-related impacts are balanced by measures taken through application of the mitigation hierarchy, so that no loss remains (TBC, 2015).
OECM (other effective area-based conservation measures)	The Convention on Biological Diversity defines OECMs as: "A geographically defined area other than a protected area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity, with associated ecosystem functions and services and, where applicable, cultural, spiritual, socio-economic, and other locally relevant values" (CBD Decision 14/8). IUCN guidance on OECMs is available here. It should be noted that most areas that qualify as OECMs have not yet been identified and included in national or international databases. Furthermore, as OECMs are defined within the context of the CBD, there may also be conserved areas governed by autonomous governance authorities (local communities, indigenous peoples, First Nations, etc.) who do not wish to be recognised under the CBD definition, and some states that may not accord them this recognition. These conserved areas nevertheless contribute towards long-term outcomes for the in-situ conservation of biodiversity (Borrini-Feyerabend & Hill, 2015) and should fall within the scope of interest of these guidelines.
Offset	Measurable conservation outcomes, resulting from actions applied to areas not impacted by the project, that compensate for significant, adverse project impacts that cannot be avoided, minimised and/or restored (TBC, 2015).
Priority biodiversity	'Priority biodiversity' refers to those biodiversity features (species and ecosystems) identified as most sensitive or highest biodiversity value for a project such as those that are of particular stakeholder concern and/or meet the criteria for 'Critical Habitat' under IFC PS6.
Proactive conservation actions (PCA)	A broad range of activities or interventions that go beyond the mitigation hierarchy and are intended to provide broad benefits to biodiversity and ecosystem services, but where the outcomes can be difficult to quantify. PCAs may or may not target biodiversity features significantly impacted by the project and can be undertaken independently of and over and above the mitigation hierarchy steps, to enhance and restore biodiversity.
Protected area	A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Dudley & Stolton, 2008).
IUCN protected areas management categories	IUCN protected area management categories classify protected areas according to their management objectives. The categories are: Ia Strict Nature Reserve; Ib Wilderness Area; II National Park; III Natural Monument or Feature; IV Habitat/Species Management Area; V Protected Landscape/ Seascape; and VI Protected area with sustainable use of natural resources (IUCN Protected Areas Categories).

Residual impacts	The remaining adverse impact on biodiversity after appropriate avoidance, minimisation and rehabilitation measures have been taken according to the mitigation hierarchy (BBOP, 2012).
Restoration	The process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed. In the context of the mitigation hierarchy, it is the 'measures taken to repair degradation or damage to specific biodiversity features of concern (which might be species, ecosystems/habitats or ecosystem services) following project impacts that cannot be completely avoided and/or minimised' (TBC, 2015). Restoration does not imply an intention to restore a degraded ecosystem to the same state and functioning as before it was degraded (which is the meaning in some specific jurisdictions, and may be an impossibly challenging or costly task). Restoration may instead involve land reclamation or ecosystem repair to return specific biodiversity features and functions, among those identified as targets for application of the mitigation hierarchy, to the ecosystems concerned (TBC, 2015).
Risk screening	A desk-based process for identifying potential biodiversity and ecosystem services risks and opportunities related with an area of interest. Risk screening are typically undertaken as part of early project planning.
Strategic environmental assessment (SEA)	A systematic process for evaluating the environmental consequences of proposed policy, plan or programme initiatives in order to ensure they are fully included and appropriately addressed at the earliest appropriate stage of decision-making on par with economic and social considerations.
Site characterisation	Process of understanding the properties of a site, including geotechnical, topographic/bathymetric, environmental, social, as well as local regulations and accessibility. In the context of renewable energy, it is most relevant to offshore wind.
Sensitive biodiversity	Those species, ecosystems and habitats that are likely to be at particular risk from a development.
Sensitivity mapping	An exercise to map the recorded or predicted presence of biodiversity features (e.g. species, sites and/or ecosystems) considered sensitive because of their importance and/or their susceptibility to impacts. Also referred to as constraints mapping.
Species	An interbreeding group of organisms that is reproductively isolated from all other organisms, although there are many partial exceptions to this rule in particular taxa. Operationally, the term species is a generally agreed fundamental taxonomic unit, based on morphological or genetic similarity, that once described and accepted is associated with a unique scientific name (IPBES).
Trophic cascade	An ecological phenomenon caused by the addition/removal of top predators and involves corresponding changes in predator and prey populations throughout the food web, which often results in dramatic changes in ecosystem structure and nutrient cycling.
Utility-scale	Refers to large-scale electricity generation which feeds energy into the grid, such as provided through solar or wind facilities at scale.

Abbreviations

ACHLI	Association for the Conservation of the Iberian-Wolf Habitat
ADB	Asian Development Bank
ADD	Acoustic deterrent device
AWWI	American Wind Wildlife Institute
BBOP	Business and Biodiversity Offsets Programme
BWEC	Bats and Wind Energy Cooperative
CBD	Convention on Biological Diversity
CHA	Critical Habitat Assessment
CIA	Cumulative Impact Assessment
CMS	Convention on Migratory Species
CSBI	Cross-Sector Biodiversity Initiative
CSP	Concentrating solar power
EBRD	European Bank for Reconstruction and Development
EIA	Environmental Impact Assessment
EMF	Electromagnetic field
EPFIs	Equator Principle Finance Institutions
ESG	Environmental, Social and Governance
ESIA	Environmental and Social Impact Assessment
E-TWG	Environmental Technical Working Group
FPIC	Free prior informed consent
F-TWG	Fisheries Technical Working Group
GBIF	Global Biodiversity Information Facility
GHG	Greenhouse gas
HSD	Hydro Sound Damper
IAS	Invasive alien species
IBAT	Integrated Biodiversity Assessment Tool
ICCA	Indigenous and Community Conserved Area
ICMM	International Council on Mining and Metals
IEA	International Energy Agency
IFC	International Finance Corporation
IFC PS6	International Finance Corporation's Performance Standard 6
IFI	International finance institution
IMMAs	Important marine mammal areas
IPIECA	International Petroleum Industry Environmental Conservation Association
IPPC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IUCN	International Union for Conservation of Nature

JNCC	Joint Nature Conservation Committee
LCA	Life cycle assessment
LED	Light emitting diode
MDBs	Multilateral Development Banks
MMO	Marine Mammal Observer
MW	Megawatts
NBSAPs	National Biodiversity Strategy and Action Plans
NGOs	Non-governmental organisations
NNL	No Net Loss
NOAA	National Oceanic and Atmospheric Administration
NYSERDA	New York State Energy Research and Development Authority
PAM	Passive Acoustic Monitoring
PBR	Potential Biological Removal
PCA	Proactive Conservation Action
PS6	Performance Standard 6
PV	Photovoltaic
PVP	Polarised light pollution
SCADA	Supervisory control and data acquisition
SDGs	Sustainable Development Goals
SDOD	Shutdown 'on demand'
SEA	Strategic environmental assessment
SeaMaST	Seabird Mapping and Sensitivity Tool
SMAs	Seasonal Management Areas
SNH	Scottish National Heritage
SPS-IEA	Stated Policies Scenario of IEA
TBC	The Biodiversity Consultancy
TCE	The Crown Estate
USAID	United States Agency for International Development
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
VECs	Valued Environmental Components

Part I

Introduction

The mitigation hierarchy

Early project planning

1. Introduction

1.1 The renewable energy transition

Achieving a low-GHG emissions, climate-resilient future, in accordance with the Paris Agreement and the Sustainable Development Goals (SDGs), necessitates rapid, sustained and far-reaching transformations in energy, land-use, urban infrastructure and industrial systems.[4] A crucial component of these transformations is the rapid scaling up of renewable energy generation.

The transition to renewable energy sources of energy is already underway. Renewable power capacity is forecast to expand by 50% between 2019 and 2024, driven by rapidly falling costs and policy reform. Solar PV is expected to account for almost 60% of this growth, followed by wind, hydropower and bioenergy.[5] Under the Stated Policies Scenario of the International Energy Agency (IEA), the continued rise in energy demand will require 8.5 Terawatt (TW) of new power installed capacity by 2040, of which two-thirds is expected to be from renewables,[6] primarily solar and wind. Corporate sourcing of renewable energy is also increasing rapidly, representing approximately 18.5% of renewable energy demand in the commercial and industrial sectors in 2018. This positions companies alongside utilities as major buyers of clean energy globally.

Large-scale expansion of renewable energy is vital for a sustainable future. However, these technologies themselves pose potential risks to biodiversity and ecosystem services. Expansion must be carefully planned and managed so that environmental benefits are maximised, and damage to nature is minimised. This is also important in securing public support and regulatory facilitation for the rapid growth needed in these sectors.

These guidelines provide a practical manual for managing risks to biodiversity and ecosystem services in wind and solar energy projects. Its aim is to help such projects achieve the best environmental outcomes, and facilitate the energy transition to wind and solar power.

1.2 Types of renewable energy

Renewable energy is obtained from natural flows of energy in our surrounding environment. Commercially viable sources include: (i) bioenergy; (ii) geothermal energy; (iii) hydropower; (iv) solar energy; and (v) wind energy.[7] Other technologies, such as wave or tidal power, are also in development but are yet to be scaleable commercially. A summary of each source and their main uses are presented in Table 1-1.

4 Díaz et al. (2019).
5 IEA (2019a).
6 IEA (2019b).
7 Owusu & Asumadu-Sarkodie (2016).

Table 1-1 Description of renewable energy sources and their main commercial uses

Renewable energy source	Summary	Uses
Bioenergy	Derived from biological sources. Traditional biomass sources, such as wood, animal waste and charcoal, are widely used for cooking and heating. More modern forms include liquid biofuels (manufactured from biomass sources, such as crops rich in starch or sugar), biogas (produced through anaerobic digestion of residues) and wood pellet heating systems. Research continues into biofuels derived from algae, which may become commercially viable in future.	Transportation using biodiesel, electricity generation, and direct use for cooking and heating
Geothermal energy	Derived from heat within the sub-surface of the earth. Geothermal resources with potential for commercial exploitation are localised, typically in tectonically active regions.	Electricity generation, and direct use for cooking, heating and cooling purposes
Hydropower	Harnessed from flowing water used to drive turbines. There are three broad types of commercial hydropower project: i) run-of-river hydropower; ii) storage hydropower; and iii) pumped-storage hydropower. Offshore hydropower (i.e. using tidal races) is less established and still largely experimental. Larger-scale projects tend to be those including a large reservoir and a dam. Smaller scale projects may not have a storage component (reservoir).	Electricity generation
Solar energy	Drawing on the sun's energy, solar irradiance is captured by photovoltaic (PV) panels or by concentrating solar power (CSP). Solar PV installations convert sunlight directly into electricity. They can be installed on land or as floating platforms. CSP uses mirrors to concentrate solar rays onto a receiver tower and standby focal points to heat fluid, creating steam to generate electricity.	PV: Electricity generation CSP: Mainly for direct lighting needs
Wind energy	Harnessed from moving air, transformed into electricity using wind turbines located onshore (land) or offshore (sea). Offshore turbines typically have fixed foundations but can also be mounted on a floating structure, which is then anchored to the bottom.	Electricity generation

General global trends show a significant rise in wind and solar power worldwide, with the largest increase in renewable energy generation by 2030 expected from wind and solar sources.[8] There have been dramatic improvements in efficiency and affordability of wind and solar technologies in recent decades. For example, onshore wind turbines improved from an average efficiency factor of about 22% in 1998 to nearly 35% in 2019.[9] However, bioenergy, hydropower and geothermal power generation show different global trends. Bioenergy is expected to maintain a steady increase, mainly to support the heating sector.[10] Hydropower accounted for the largest share of total renewable energy generation in 2020, but is forecast to decline globally.[11] Although geothermal growth is predicted to increase, exploitable geothermal power is limited to a small number of countries and is forecast never to reach the global capacity additions expected of solar and wind.[12]

8 IRENA (2019c).
9 US Department of Energy (n.d.).
10 IEA (2019a).
11 IEA (2012).
12 IEA (2019a).

1.3 Biodiversity, ecosystem services and renewable energy

Use of any energy source can potentially impact biodiversity. Impacts for different energy sources can be compared using life-cycle assessments (LCAs) that take into account all stages of extraction, production and use, and the full set of potential impacts. This includes impact sources that may not be easily visible, such as from extraction of raw materials, pollution and climate change. Such assessments show that deriving energy from solar and wind developments is far less environmentally damaging overall than using fossil fuels, including coal and natural gas.[13]

Wind and solar developments can nevertheless also pose risks to biodiversity (Box 4 and Section 2.2). Land or sea occupancy is one of the most visible impacts for any energy development. For renewables, the land or sea area required per unit energy varies according to conditions and technology, but is typically greater than for natural gas, coal or nuclear energy.[14] Estimates for the USA show broadly comparable land takes for wind, hydropower and solar PV (with wind the highest on average), all also broadly comparable to oil extraction.[15] Geothermal and CSP require smaller land takes per unit energy, broadly on a par with natural gas and coal, while biofuels require far more (around an order of magnitude greater) than other renewables.[16]

The relatively large land take for wind and solar highlights the importance of good mitigation practice to help facilitate the transition into renewable energy. Fortunately, the abundance of solar and wind energy means that, unlike other energy sources, there is often flexibility in project siting, allowing the use of already converted or disturbed land or offshore locations away from areas of high sensitivity, including, for example closed landfill sites.[17] Careful siting and planning of wind and solar projects can thus help to avoid many significant impacts and provide broad support for their development. By contrast, large-scale hydropower – while also a low-carbon energy source with comparable land take – is often highly constrained by location, with pervasive impacts upstream and downstream that are difficult to mitigate.

For wind and solar projects, there is often also a potential to maintain or restore biodiversity within the infrastructure matrix. In some cases, this can generate positive biodiversity impacts. For example, solar farms placed in modified habitat can provide biodiversity enhancement opportunities when well designed and managed,[18] while offshore wind farms can create refuges for benthic habitats, fish and marine mammals.[19]

Wind energy is often criticised for its negative impacts on birds and bats. Wind turbines potentially present a risk to particularly vulnerable species groups such as birds of prey. However, studies examining the full suite of impacts show that power generation from fossil fuels poses a much greater (if less obviously visible) threat to birds and bats, mainly due to the associated impacts from pollution and climate change. As with land take, careful siting of wind projects away from sensitive areas can help to avoid or reduce potential impacts to flying species (Section 3).

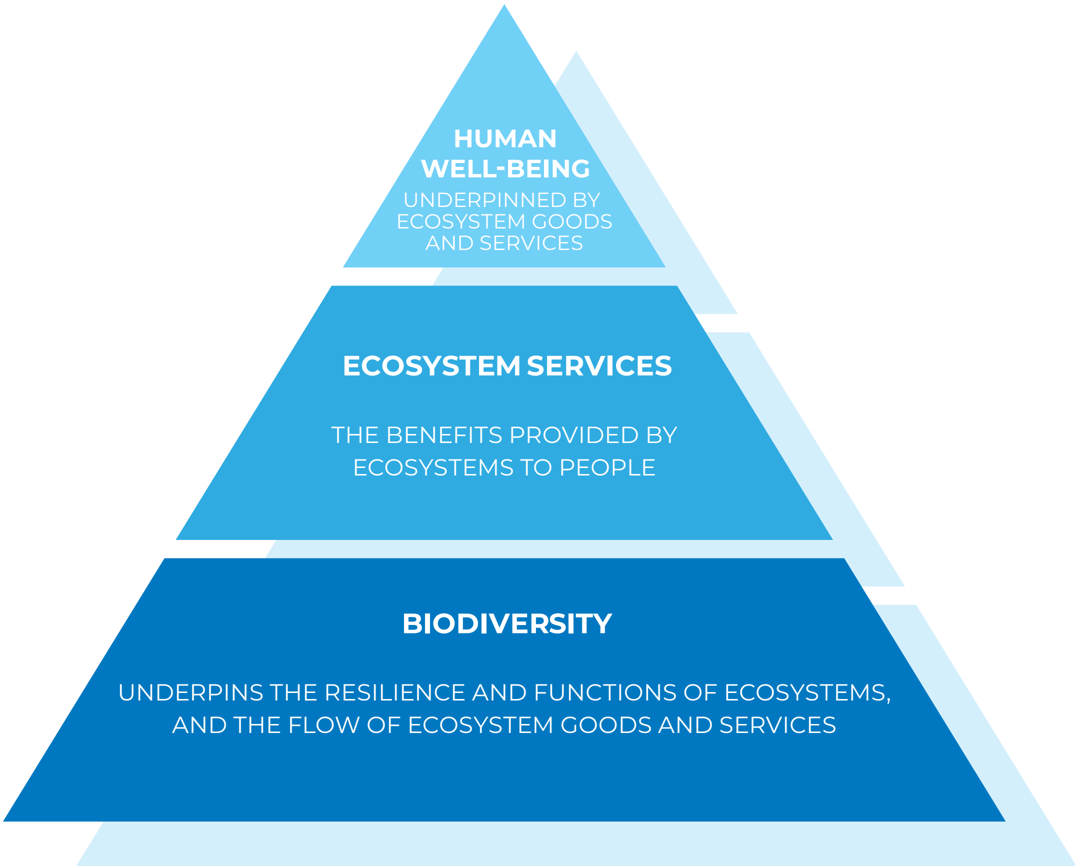
Solar and wind developments need to consider not only potential impacts to biodiversity but also associated risks to the continued delivery of ecosystem services, i.e. the benefits and values that people obtain from natural resources. If not carefully managed, such developments can change the supply of, or limit access to, ecosystem services, including provisioning services, such as food and water as well as recreational, cultural (including a sense of place and belonging) and other non-material benefits (Figure 1.1). In turn, this can impact the livelihoods and well-being of local people, particularly those

13 See Luderer et al. (2019); UNEP (2016).
14 McDonald et al. (2009).
15 Ibid.
16 Ibid.
17 Szabó et al. (2017).
18 Montag et al. (2016).
19 Coates et al. (2014); Hammar et al. (2015); Krone et al. (2013); Lindeboom et al. (2011).

who heavily depend on such services for their daily sustenance, health, security and jobs. Developments should also not undermine the rights of indigenous peoples and marginalised and disadvantaged groups such as women and youth.

Where these goods and services are compromised, it can generate conflict. A common source of public opposition to wind developments is the visual impact they can have to the landscape and people. For example, permission to develop a wind farm near a World Heritage Site in South Africa, which was recently overturned, would not only have impacted birds, but also the peoples' view and "sense of place".[20] Such impacts to scenic landscapes can be perceived as highly negative, and are difficult to mitigate. Where significant potential impacts to ecosystem services exist, accounting for and addressing these is essential to the long-term success of renewable energy development.

Figure 1.1 Relationship between biodiversity, ecosystem services and human well-being



20 Yeld (2019).

2. The mitigation hierarchy

The mitigation hierarchy provides developers with a logical framework to address the negative impacts of development on biodiversity and ecosystem services. It is applicable to projects in any sector, including renewable energy, and is based on the sequential and iterative application of four actions:[21] avoid, minimise, restore and offset. This section introduces the types of impacts referred to throughout the guidelines, and presents ways with which mitigation hierarchy can address them and achieve project biodiversity goals.

The following sections present detailed recommendations for implementing the mitigation hierarchy:

- Section 3: Early project planning
- Section 4: Solar energy – potential impacts and mitigation approaches
- Section 5: Onshore wind energy – potential impacts and mitigation approaches
- Section 6: Offshore wind energy – potential impacts and mitigation approaches
- Section 7: Implementation of biodiversity offsets and proactive conservation actions

Annex 1 provides references to additional guidance on application of the mitigation hierarchy.

2.1 Types of impacts

These guidelines address three broad types of impacts: direct, indirect and cumulative (Figure 2.1). Additional impacts related to procurement are covered in Section 10. Impacts can occur to both biodiversity and ecosystem services, defined as:

Impacts to *biodiversity* are changes to any components of biodiversity, including genes, species or ecosystems, whether adverse or beneficial, wholly or partially, resulting from a project's actions. *Biodiversity loss* describes the decline in the number, genetic variability, and variety of species, and the biological communities in a given area. This loss can in turn lead to a breakdown in the functioning of the ecosystem and the services it provides to people.

Impacts to *ecosystem services* are impacts to the benefits and values that people derive from a functioning ecosystem. Ultimately, such impacts can negatively affect human well-being (Figure 1.1).

i. **Direct impacts.** Impacts that result from project activities or operational decisions that can be predicted based on planned activities and knowledge of local biodiversity, such as habitat loss under the project footprint, habitat fragmentation as a result of project infrastructure and species disturbance or mortality as a result of project operations. Such impacts can also lead to a reduction in the delivery of ecosystem services, for example, by reducing or restricting access to land that was previously available for natural resource collection.

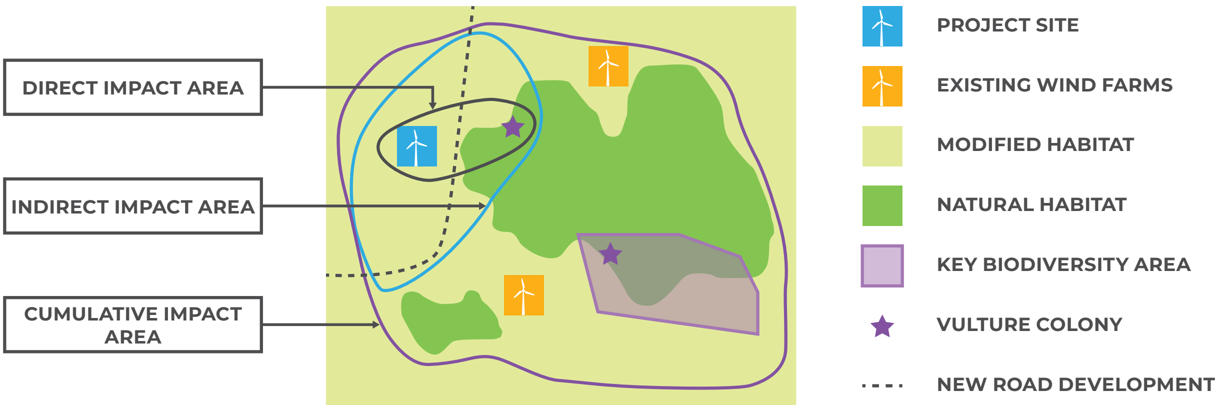
ii. **Indirect impacts.** Impacts induced by, or 'by-products' of, project activities within a project's area of influence. For example, indirect impacts to biodiversity can arise because of

21 Cross Sector Biodiversity Initiative (CSBI) (2013); The Biodiversity Consultancy (TBC) (2015). These Guidelines follow CSBI's definition of mitigation hierarchy. To note, there are alternative approaches to implementing the mitigation hierarchy to achieve the same result, such as that detailed in May (2017), which advocates a five-step approach tied to the decision gates for wind farm development: 1) avoid when planning, 2) minimise while designing, 3) reduce at construction, 4) compensate during operation, and 5) restore as part of decommissioning.

increased migration of people into an area in search of economic opportunities, creation of routes into previously inaccessible areas ('induced access') or displacement of people into previously undisturbed areas. This can lead to increased pressure on biodiversity or unsustainable use of ecosystem services through, for example expansion of agriculture, tree-cutting, hunting or fishing. Predicting the scale of indirect impacts is often difficult as they arise from interactions of multiple external factors with the project.

iii. **Cumulative impacts.** Impacts that result from the successive, incremental and/or combined effects of existing, planned and/or reasonably anticipated future human activities in combination with project development impacts. They may arise from multiple projects in one sector (such as wind energy) and/or due through pressures from many sectors and sources (sometimes referred to as 'aggregated' or 'in-combination' impacts). Cumulative impacts can be highly significant for sensitive species and ecosystem services but are often overlooked (Section 3.2 for a more detailed discussion).

Figure 2.1 Relationship between direct, indirect and cumulative biodiversity impacts – Illustrative example of an onshore wind development within an area important for vultures



2.2 Components of the mitigation hierarchy

Implementing the mitigation hierarchy[22] is an iterative process – not a linear one – that involves feedback and adaptive management. Avoidance and minimisation measures prevent or reduce impacts, while restoration and offset measures remediate impacts that have already happened. Preventive actions are preferable from an economic, social and ecological perspective for lenders, regulators and other stakeholders. Compared to avoidance and minimisation, restoration and offset measures tend to have less certainty of success and come at a higher cost to the developer.

Application of the mitigation hierarchy in full implies an overall target, or goal, for the biodiversity and ecosystem services outcomes associated with a project, such as No Net Loss (NNL) or Net Gain (Section 2.5). To be able to assess against such outcomes, the mitigation hierarchy steps will need to provide a measurable reduction to the overall project impact.

The mitigation hierarchy is comprised of a sequence of four steps:

- **Avoidance** is the first and most important step of the mitigation hierarchy. It is based on measures taken to anticipate and prevent the creation of impacts. For avoidance to be effective, biodiversity risks need to be identified early in the project planning stages, or opportunities

22 CSBI (2013).

will be missed. Effective avoidance can occur through site selection (to ensure projects are not located in areas of high risk (Section 3), project design (to locate infrastructure and select designs that avoid impacts) and scheduling (to ensure the timing of project activities is favourable for biodiversity).

- **Minimisation** refers to measures taken to reduce the duration, intensity and/or extent of impacts that cannot be completely avoided, as far as is practically feasible. Potential minimisation measures can be identified during early planning, and when developing design alternatives to be considered. Measures to minimise impacts can be applied throughout the project cycle, from design through construction, operations and closure, decommissioning and repowering.

Minimisation actions fall into three broad categories:

- **Physical controls:** adapting the physical design of project infrastructure to reduce potential impacts such as reducing habitat fragmentation through the installation of culverts or installing bird flight diverters on transmission lines.
- **Operational controls:** measures taken to manage and regulate the actions of people, including project staff and contractors, such as restricting access to sensitive sites within the project area.
- **Abatement controls:** steps taken to reduce levels of pollutants (e.g. light, noise, gases or liquids) that could have negative biodiversity impacts.

Minimisation and avoidance are closely related, although minimisation does not provide the same level of mitigation certainty that avoidance does. Whether an action can be considered as avoidance or minimisation is a matter of circumstances and scale. For example, relocating a planned wind farm to completely avoid an important migratory corridor for birds could be considered avoidance through site selection (Section 3). Shutting down turbines during periods of high bird activity to reduce the number of bird collisions with turbine blades would be considered minimisation.

- **Restoration:** There are many terms linked to restoration, including rehabilitation, reclamation and remediation. In the context of the mitigation hierarchy, restoration refers to measures that aim to repair specific biodiversity features or ecosystem services damaged by project impacts that could not be completely avoided or minimised. This differs from general rehabilitation, which may not set out to restore the original biodiversity or the biodiversity components on which ecosystem services depend. As a mitigation hierarchy step, restoration is also distinct from interventions to offset project impacts by restoring biodiversity elsewhere (see next bullet). Restoration is typically undertaken either during construction (to address impacts from temporary facilities such as laydown areas or roads), or towards the end of a project as part of decommissioning and/or repowering.
- **Offsets** are measures taken to compensate for significant adverse residual impacts that cannot be avoided, minimised or restored (Section 7). Offsets should only be considered as a last resort to address residual impacts on biodiversity, and only after all avoidance, minimisation and restoration options have been exhausted. Offsets aim to achieve a measurable conservation outcome for the biodiversity features they target.[23] Offsets involve positive conservation interventions to generate biodiversity gains either through **avoided loss** (addressing threats to prevent predicted biodiversity loss) or **restoration** (for example, improving the quality of degraded habitat). Government regulators and lenders increasingly require biodiversity offsets to address residual impacts and achieve no net loss or net gain outcomes (Section 2.5).[24] A growing number of businesses are also adopting voluntary biodiversity commitments that also aim to achieve no net loss or net gain outcomes.[25] Offsets can be complex and expensive to implement. Fortunately, wind and solar projects can usually avoid the need for offsets through careful siting and effective minimisation measures that reduce residual impacts to negligible levels. Offsets produce measurable gains for the biodiversity features they target.

23 IUCN WCC (2016).
24 GIBOP (2020).
25 de Silva et al. (2019); Rainey et al. (2014).

Other conservation actions that can be undertaken independently of, and over and above the mitigation hierarchy steps, to enhance and restore biodiversity are termed Proactive Conservation Actions (PCAs) (Box 1).

Application of the mitigation hierarchy is illustrated for developments planned in areas of low biodiversity sensitivity (Figure 2.2) and high biodiversity sensitivity (Figure 2.3). Selecting a site with low biodiversity sensitivity for wind or solar developments, such as on land that is already converted for agricultural or other use, reduces potential impacts and the need for mitigation measures. When the development has no significant residual impacts, positive biodiversity outcomes can be achieved through enhancement of biodiversity on site. Developments on sites with higher biodiversity sensitivity are likely to have more demanding and expensive mitigation requirements. To achieve net gain goals, they may require offsets, which frequently pose practical and reputational challenges (Section 7). The approach to apply the mitigation hierarchy through the project cycle is presented in the next section (Section 2.4).

Box 1 Proactive Conservation Actions

Opportunities often exist to go beyond traditional mitigation practice and deliver additional benefits to biodiversity and ecosystem services. Developers can take these opportunities to work proactively with stakeholders, identifying and delivering positive outcomes that contribute to wider environmental and societal priorities and also demonstrate good environmental stewardship.

These guidelines refer to such activities as **Proactive Conservation Actions (PCAs)**, in line with terminology used in the emerging Conservation Hierarchy framework. PCAs are also referred to as 'additional conservation actions' (ACAs), particularly within the extractive industry. Both PCAs and ACAs refer to project activities that either produce gains that are not easily measurable (e.g. research and training) or that are not targeted at the biodiversity impacted by the development (e.g. habitat enhancement for pollinators around wind turbine sites).

The implementation of PCAs to deliver positive conservation outcomes is discussed further in Section 7, with examples provided through Box 18 and case studies 5, 12, 16, 17, 21 and 22 in Annex 2.

2.3 The mitigation hierarchy across the project cycle

The mitigation hierarchy can be applied throughout a project's life cycle, from early planning and design, through to construction, operations and eventual decommissioning and repowering. Effective application includes identification of site alternatives, design modifications and continual evaluation and improvement, with the aim of driving optimal investment into early avoidance and minimisation, and reducing or even completely avoiding the need for restoration and offsets. Figure 2.2 illustrates the mitigation hierarchy across the project lifecycle, showing the component(s) of the mitigation hierarchy relevant at each stage. Figure 2.3 illustrates how a project can move through the mitigation hierarchy with key mitigation checks and actions during project development.

Figure 2.2 Applying the mitigation hierarchy in an area of low biodiversity sensitivity. Impacts at the site can be further reduced through project design to minimise impacts. On-site habitat enhancement actions help to achieve no net loss or net gain to biodiversity

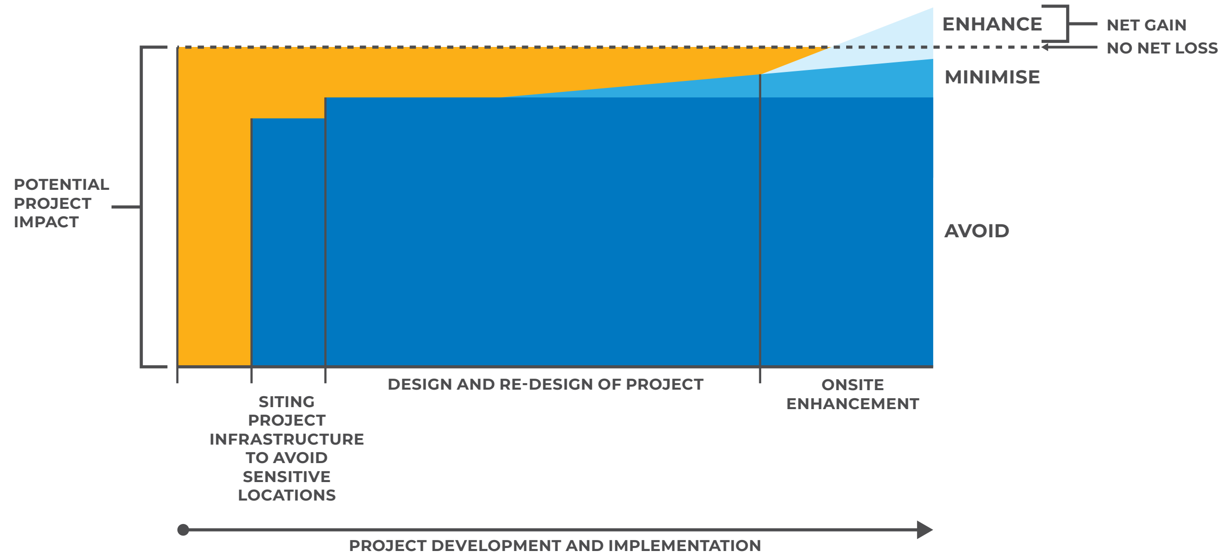


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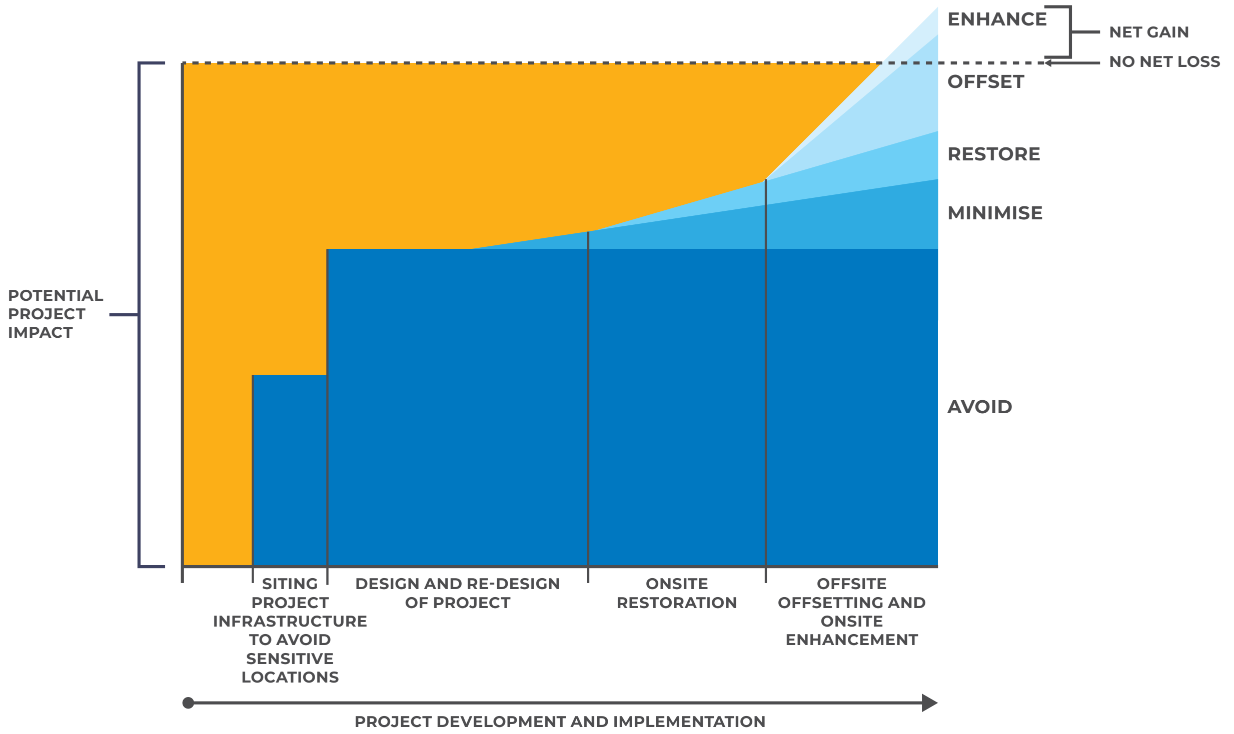
Figure 2.3 Applying the mitigation hierarchy in an area of high biodiversity sensitivity. Ideally such sites would be avoided through early planning. Where this is not feasible, on-site impacts can be minimised through project infrastructure siting and project design. On-site restoration may be needed to further reduce impacts. Off-site offsets may be required to achieve no net loss or net gain to biodiversity. Offsets are inherently difficult and uncertain and should only be used as a last resort. There may be limited opportunities to undertake on-site habitat enhancement



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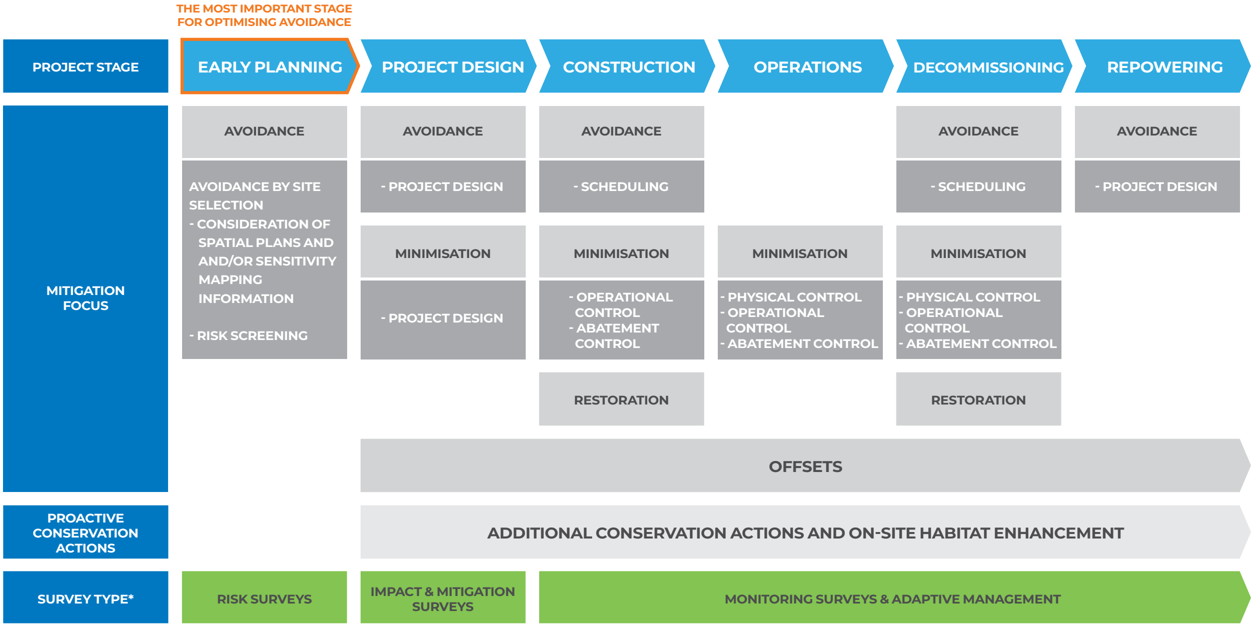
2.4 Principles of good mitigation practice

Experience in mitigating biodiversity impacts across a variety of sectors suggests a number of overarching principles for good practice mitigation that apply equally to renewable energy (Table 2.1). Following these principles can facilitate renewable energy expansion, while ensuring that biodiversity and ecosystem service risks are identified, accounted for, and effectively managed.

Annex 1 provides references to additional guidance and standards on good mitigation practice.

Figure 2.4 Applying the mitigation hierarchy across the project development cycle, including mitigation components relevant at each stage



*The type of surveys needed to assess and monitor biodiversity risk, impacts and mitigation.

Figure 2.5 Moving through the mitigation hierarchy – Key mitigation checks and actions during project development

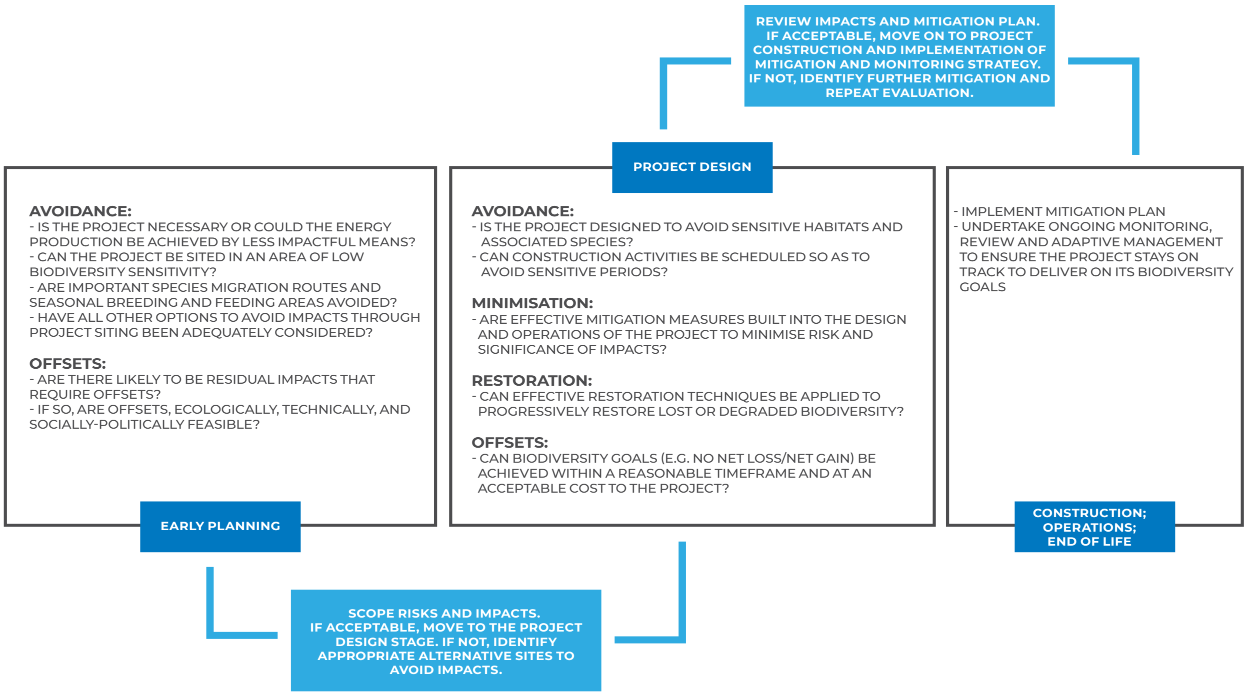


Table 2-1 Overarching principles for good practice mitigation

Overarching principles	Specific aspects
1. Consider biodiversity and landscape-scale risks at the earliest stage of project planning	• Strategic-level planning exercises at national or regional scale that identify suitable sites for wind and solar energy development in areas of low biodiversity sensitivity are invaluable in de-risking development. Where strategic assessments do not yet exist, it may be beneficial for developers to encourage the production of such assessments, facilitate them with the relevant and appropriate stakeholders, or undertake their own assessment to inform project siting. • Early identification of risks to biodiversity, through screening as part of project planning, is critical to avoiding significant impacts. In areas of low biodiversity sensitivity, mitigation is likely to be relatively straightforward and inexpensive. By contrast, in areas of high biodiversity sensitivity, mitigation options may be limited, costly, unpredictable and, in some cases, unattainable. • Early risk screening should identify important biodiversity features and potential project impacts at suitably large, ecologically-coherent scales, and should consider seasonality. All elements of project infrastructure and impact types (direct, indirect, cumulative) should also be considered. Note: Tools and approaches for strategic planning and early identification of risks are presented further in Section 3 (Early project planning).
2. Apply the mitigation hierarchy rigorously	• The mitigation hierarchy is a central element of good practice for managing and mitigating impacts on biodiversity and ecosystem services. It prioritises prevention over remediation through rigorous application of the mitigation hierarchy to avoid and minimise to the fullest extent feasible. Applying the mitigation hierarchy is an iterative process – it may often be necessary to revisit the steps more than once, for example reviewing project design to ensure that residual impacts are driven down to as low a level as possible. Offsets should only be considered as a last resort to address residual impacts, and only after all avoidance, minimisation and restoration options have been exhausted. • Wind and solar energy developments often provide opportunities to go beyond traditional mitigation practice and create further/additional biodiversity benefits, for example through on-site habitat enhancement. Such proactive conservation actions (PCAs) can help amplify the positive environmental impacts of renewable energy and build stakeholder support for scaling up these technologies. Note: Section 7 addresses implementation of offsets and PCAs.
3. Recognise peoples' rights and needs in planning biodiversity mitigation	• Environmental and social issues need to be considered together, as indigenous peoples and local communities may derive many benefits from their environment. A project's approach to biodiversity mitigation (and especially biodiversity offsets) needs to ensure that the livelihoods and well-being of indigenous peoples and local communities are not negatively impacted. In addition, all development should aim and ensure projects result in just outcomes, where those with the least prospects are not marginalised. Not doing so may undermine a project's social goals and the effectiveness of conservation interventions, which rarely succeed without the support and positive engagement of local communities. • Financial institutions will be sensitive to renewable energy projects where there is potential for adverse impacts on local communities, and where indigenous people also have heighted reputational risk. In some cases, projects may need to provide alternative livelihood opportunities or compensation. Note: Further information on this is provided in Section 7.3 (seeking better outcomes for people when mitigating biodiversity loss from development).
4. Carry out the right surveys to understand risks	• Field surveys are needed to validate desk-based findings and identify any additional risks (Section 8), even in areas identified as lower-sensitivity. Risks may appear lower as a result of data deficiency; therefore, it is important to understand the quality and reliability of the data supporting the assessment. As biodiversity (and associated social) risk increases, so does the level of certainty required for assessment and monitoring. • For projects planning to operate in highly sensitivity areas, comprehensive surveys will be needed to assess both biodiversity and social risk (including feasibility of offsets), plan mitigation and monitor the effectiveness of mitigation measures. • Scoping of field surveys needs to consider the appropriate geographic and temporal scales for priority biodiversity features and types of impacts, including direct, indirect and cumulative. Open and transparent communication and sharing of monitoring results not only help developers comply with regulations – it is also increasingly recognised as good practice that can help generate credibility and support for their project with stakeholders and help contribute to wider conservation efforts. Note: Good practice approaches for monitoring are discussed further in Section 8 (Assessment, monitoring and evaluation).

2.5 Project biodiversity goals

Full application of the mitigation hierarchy implies a measurable goal of at least 'no net loss', but preferably a 'net gain' of targeted biodiversity features[26] (Figure 2.2):

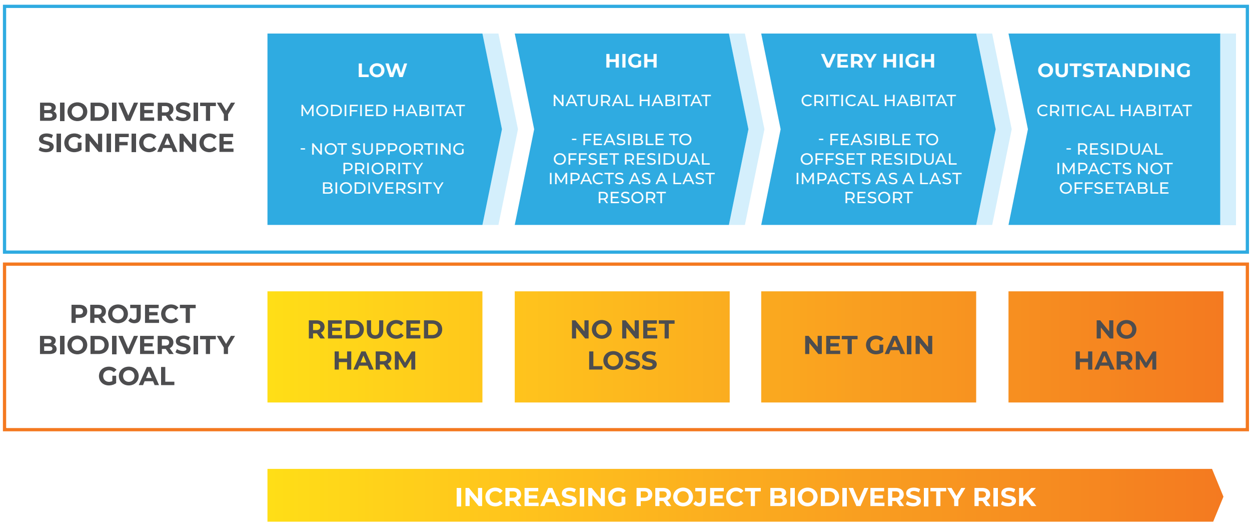
- 'No net loss' is defined as the point at which project-related impacts are balanced by mitigation hierarchy measures, so that no losses remain.
- 'Net gain' is defined as the point at which project-related impacts are outweighed by measures taken according to the mitigation hierarchy, resulting in a net gain of the relevant biodiversity features. This is also referred to as Net Positive Impact.

The overall goal may depend on the requirements and views of regulators, financers and stakeholders (Figure 2.6). For example, the goal of 'do no harm' is also used in some frameworks such as in the EU Taxonomy for sustainable financing. Goals may also depend on the biodiversity significance of the area.

IFC's Performance Standard 6, a widely applied standard, requires a no net loss to Natural Habitat[27] and a net gain for projects operating in Critical Habitat.[28] In some cases, regulators may set sectoral requirements for impact compensation so that projects contribute to achieving national conservation targets (Section 7.4).

Measuring and tracking progress towards biodiversity and ecosystem service goals requires a framework and process for accounting for the losses and gains at each stage of the mitigation hierarchy. Where residual impacts remain, offsets will be required to meet goals. An indicative process for assessing progress against goals through application of offsets is outlined in Figure 2.6. Details on the implementation of offsets are given in Section 7. Annex 1 provides references to additional guidance on the principles, design and implementation of offsets, including how to choose and assess suitable biodiversity metrics.

Figure 2.6 Example of how an appropriate biodiversity goal for a project can be defined based on the biodiversity significance of the area



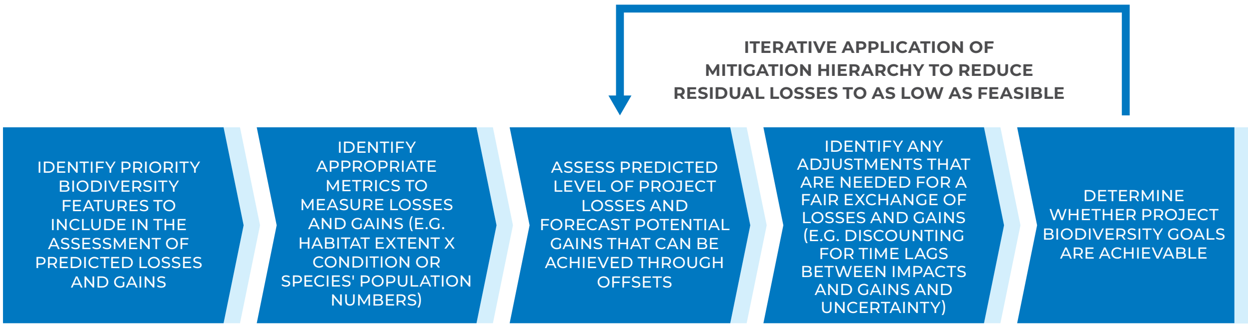
Note: This is a schematic example; the appropriate goal will be project specific, and depend on the requirements and views of regulators, financers and stakeholders

26 Biodiversity features can include both species and ecosystems, and are often referred to as 'priority biodiversity features'.

27 IFC (2012) defines Natural Habitats as areas composed of viable assemblages of plant and/or animal species of largely native origin, and/or where human activity has not essentially modified an area's primary ecological functions and species composition.

28 In IFC's Performance Standard 6 (2012), features of high biodiversity value (as determined through an assessment of species, ecosystems and ecological processes against a series of quantitative and qualitative criteria) are termed 'Critical Habitat'. Internationally recognised and legally protected areas may also qualify as Critical Habitat. The term 'critical habitat' is also used (and defined differently) in the U.S. Endangered Species Act. See the Glossary for more detail.

Figure 2.7 Indicative process to identify, measure and mitigate impacts to biodiversity to achieve no net loss or net gain outcomes



Note: This is a schematic example; the appropriate goal will be project specific, and depend on the requirements and views of regulators, financers and stakeholders

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2.6 The role of policy in biodiversity mitigation practice

A number of key policy drivers and mechanisms exist to mainstream good biodiversity mitigation practices into the renewable energy sector. These mechanisms and drivers can be grouped into four general categories: (i) multilateral environmental agreements; (ii) national policies and legislation; (iii) international finance standards; and (iv) corporate policies and standards.

The degree to which these apply and serve to facilitate effective implementation of biodiversity mitigation at the strategic and project levels depend on both the national regulatory and financing environment. In turn, policies and standards at the project level can be informed by multilateral agreements between countries.

International agreements related to biodiversity play a critical role in setting the agenda for international policy that influences national policies and legislation. They include the major multilateral environmental agreements, which are intergovernmental treaties. Agreements serve to guide action on biodiversity issues at international, regional and national levels. Selected key agreements relevant to renewable energy development and biodiversity conservation are summarised in Table 2-2. This list is not exhaustive.

National policies, strategies and regulations set the enabling conditions for good biodiversity mitigation practices for renewable energy development. Spatial planning (potentially informed by Strategic Environmental Assessment, SEA) is particularly important in identifying appropriate sites for renewable development away from areas of high biodiversity sensitivity (Section 3). ESIAs provide the main legislative instrument for approving individual developments and enforcing mitigation practice (Section 3.5). The protected status of certain species often carries specific regulatory requirements such as avoiding harm or achieving no net loss or net gain requirements for those species.

Environmental standards from international finance institutions (IFIs) play an influential role in managing a business approach to biodiversity and ecosystem services risk management, where standards are becoming increasingly stringent. Access to finance remains a key driver for good biodiversity practice, particularly in emerging markets. Particularly influential to large-scale developments are the eight IFC Performance Standards (PS), including PS6 on Biodiversity Conservation and Sustainable Management of Living Natural Resources, PS7 on Indigenous Peoples and PS8 on Cultural Heritage. The IFC has also developed Environmental, Health and Safety Guidelines for Wind Energy.[29]

29 See also IFC's (2007); EHS Guidelines for Electric Power Transmission and Distribution.

Table 2-2 Summary of key biodiversity-related international agreements relevant to renewable energy development

Agreement	Summary
Convention on Biological Diversity (CBD) Post-2020 Biodiversity Framework	The Convention on Biological Diversity is the overarching multilateral environmental agreement for biodiversity, with 196 Parties comprising nearly all the world's countries. The CBD's post-2020 global biodiversity framework will build on the Strategic Plan for Biodiversity 2011–2020 and sets out an ambitious plan to implement broad-based action to bring about a transformation in society's relationship with biodiversity and to ensure that, by 2050, the shared vision of living in harmony with nature is fulfilled.
Bern Convention on the Conservation of European Wildlife and Natural Habitats	A binding international legal instrument in the field of nature conservation, covering most of the natural heritage of the European continent and extending to some counties in Africa.
Convention on the Conservation of Migratory Species of Wild Animals (CMS)	An intergovernmental treaty with global remit. CMS lists a number of migratory species that are susceptible to wind and solar impacts for which parties to the convention have agreed increased protection. CMS convenes the Energy Task Force, a dedicated multi-stakeholder platform that works towards reconciling renewable energy developments with the conservation of migratory species. There are a number of other relevant agreements and memorandums under the CMS umbrella, including the Agreement on the Conservation of African-Eurasian Migratory Birds (AEWA), the Memorandum of Understanding on the Conservation of Migratory Birds of Prey in Africa and Eurasia (Raptors MOU), the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS), and the Agreement on the Conservation of Populations of European Bats (EUROBATS).
United Nations Sustainable Development Goals (SDGs)	Seventeen SDGs were adopted by all UN Member States in 2015, as part of the 2030 Agenda for Sustainable Development, which set out a 15-year plan to achieve the Goals. SDGs, relevant to renewable energy and biodiversity include: GOAL 7: Affordable and Clean Energy - Ensure access to affordable, reliable, sustainable and modern energy GOAL 13: Climate Action - Take urgent action to combat climate change and its impacts GOAL 14: Life Below Water - Conserve and sustainably use the oceans, seas and marine resources GOAL 15: Life on Land - Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss
Conservation of Arctic Flora and Fauna (CAFF) – Arctic Migratory Birds Initiative (AMBI)	The AMBI has identified priority species and conservation actions for Arctic migratory birds threatened by overharvest and habitat alteration outside the Arctic, especially along the East Asian Flyway.
East Asian - Australasian Flyway Partnership (EAAFP)	An informal and voluntary partnership of countries, intergovernmental agencies, international NGOs and private enterprise, aiming to protect migratory waterbirds, their habitat and the livelihoods of people dependent upon them in this important flyway.
Ramsar Convention on Wetlands	An intergovernmental treaty providing the framework for national action and international cooperation for the conservation of wetlands and their resources.
World Heritage Convention	An intergovernmental treaty under which sites of global natural or cultural importance are identified and protected.

Box 2 European Commission's guidance document on "Wind energy developments and EU nature legislation"[30]

In 2020, the European Commission released an update to the 2011 guidance document, providing clarifications for the interpretation and application of EU nature legislation (Birds[31] and Habitats[32] Directives) relevant to both onshore and offshore wind energy developments.[33] The guidance is part of the broader set of guidance documents[34] published by the European Commission to facilitate the implementation of the EU nature laws.

The main aim of the updated guidance document is to reflect the latest developments in EU policies and legislation on renewable energy and nature protection, as well as the developments in wind energy technology since its initial publication in 2011. It gathers the latest information on the possible impacts of wind energy activities on biodiversity and the available mitigation practices to address them. The document covers the whole life cycle of wind energy developments, both on land and at sea, and explains the necessary steps to ensure that the activities related to wind energy are compatible with EU environmental policy in general and EU nature legislation in particular.

The European Commission's guidance document is a useful additional resource for information on potential biodiversity impacts and mitigation measures for wind energy development within the European context and is broadly aligned with the recommendations presented in these guidelines.

A large number of other financial institutions have broadly aligned their own environmental standards with IFC PSs through the adoption of the Equator Principles. Other major development banks have standards that apply similar principles and requirements, including the:

- World Bank's Environmental and Social Framework;
- European Bank for Reconstruction and Development (EBRD) Performance Requirements;
- Asian Development Bank (ADB) environmental safeguards policy; and
- Inter-American Development Bank (IDB) Environmental and Social Policy Framework (ESPF).

Similarly, export credit agencies are increasingly applying similar standards through the OECD Common Approaches. Private and public investors, such as pension funds and asset managers, are also keenly aware of the potential reputational and credit risks associated with biodiversity and ecosystem service risks and are increasingly aligning their investment policies with IFI standards.

Corporate policies and standards increasingly align with good practice biodiversity standards, with a growing number of companies moving towards net positive or similar voluntary commitments.[35] Doing so can help businesses align with increasingly stringent regulatory requirements, maintain access to finance and gain a competitive advantage through enhanced brand image.[36] By setting science-based targets for nature, business can measure and report on impacts across their value chain, and demonstrate they are operating within a safe space for nature. Further guidance on developing, measuring and communicating corporate biodiversity goals, including net gain targets, can be found in Annex 1.

30 EC (2020).
31 EU (2009).
32 EU (1992).
33 EC (2020).
34 EC (n.d.).
35 Business for Nature (n.d.); Rainey et al. (2014).
36 TBC, (2018a).


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3. Early project planning

3.1 Overview

The **early project planning phase** includes an assessment by developers of the feasibility of potentially suitable project site(s) based on a range of criteria (Box 3). These typically include solar or wind potential, availability of land for purchasing or long-term leasing, access to the transmission network and environmental and social considerations.

Significant biodiversity impacts can often be avoided entirely by placing renewable energy developments on previously converted sites such as agricultural lands and other types of modified habitat (Annex 2, case studies 4 and 15). For example, solar PV developments in agricultural lands, often referred to as 'agrivoltaics', can reduce the conversion of natural land while also increasing land productivity.[37] The decentralisation of renewable energy systems through roof top solar, for example, can also be considered to help avoid the impacts associated with large scale developments and the associated infrastructure.[38] Fortunately, the relative abundance of solar and wind energy means there is often some flexibility in siting.[39] Investment in re-powering of existing sites can also be a strategy to avoid creating additional impacts.[40]

Ideally, effective avoidance through site selection will be informed by existing spatial plans developed before permitting starts (Annex 2, case studies 25, 29 and 32).

Box 3 Early project planning

Early planning is an iterative process to develop an understanding of project-specific risks, costs and expected revenues. This enables an assessment of project feasibility, and decisions about where to site the project and whether to take it forward into the design stage.

Early planning informs **avoidance through site selection**, the most effective mitigation measure available to renewable energy developers. At this early stage, it is feasible to make changes to infrastructure siting and operational planning, with potential for large reduction in project risks and requirements for further mitigation. A key strategy to reduce project risks focuses on avoiding siting solar or wind projects in areas of high biodiversity, including protected areas and conserved areas, World Heritage Sites or other areas of high biodiversity significance such as Key Biodiversity Areas (Boxes 4 and 7, and case study 2). In addition, projects need to consider potential impacts to ecosystem services and the diverse societal rights, and only proceed after free prior and informed consent (FPIC) of the affected communities (Box 9).

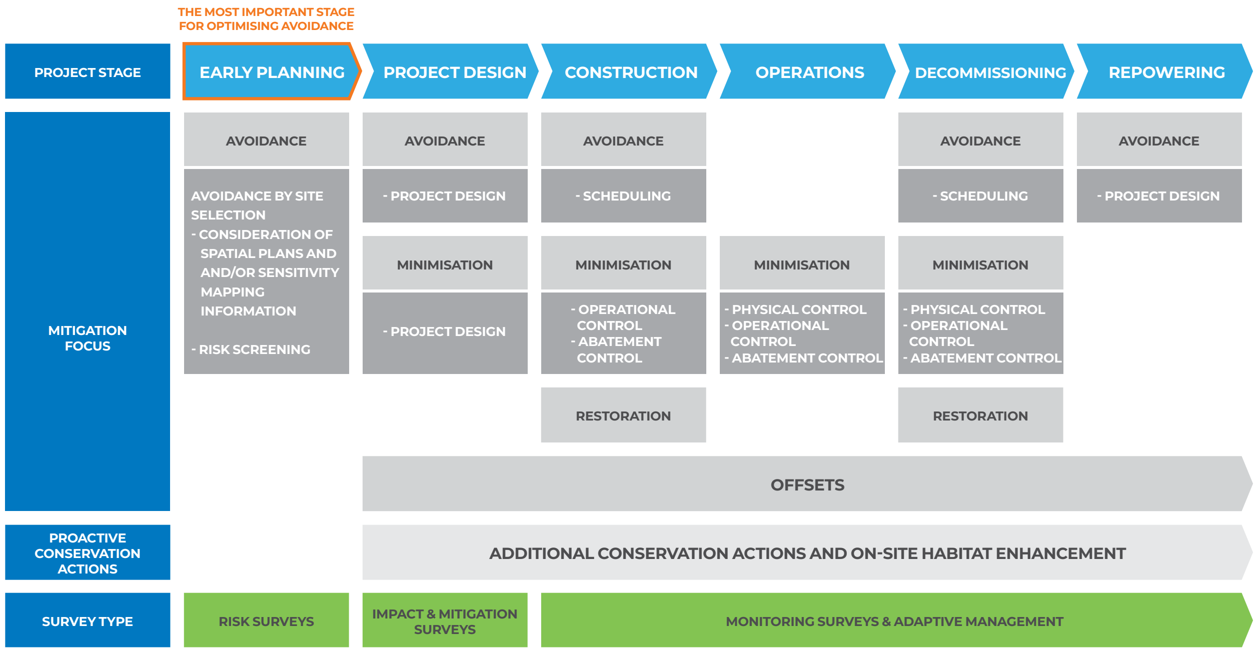
37 Amaducci et al. (2018); Barron-Gafford et al. (2019); Dinesh & Pearce (2016).
38 IUCN WCC (2012a; 2012b).
39 This may not always be the case. Wind energy, in particular, can be a highly localised resource.
40 Mitigation through project repowering is presented separately for solar, onshore wind and offshore wind developments.

Box 4 Risks of wind and solar expansion to Key Biodiversity Areas

Key Biodiversity Areas (KBAs) are defined as 'sites contributing significantly to the global persistence of biodiversity, in terrestrial, freshwater and marine ecosystems'.[41] The Global Standard for the Identification of Key Biodiversity Areas[42] sets out globally agreed criteria for KBAs identification worldwide. Industrial expansion, including renewable energy, presents a significant and growing risk to these areas. An assessment by Rehbein et al.[43] found that ~17.4% of large-scale (>10 MW) renewable energy facilities comprised of wind, solar (PV) and hydropower globally operate within the boundaries of important conservation areas, including KBAs. Of the total projects, 559 wind power developments and 201 solar (PV) developments, or respectively 9% and 7% of all projects, currently operate within KBAs. Another 162 wind and 152 solar projects are currently under development within KBAs. The expansion of renewable energy into new regions, such as Southeast Asia, is of particular concern, given its global biodiversity significance. Research by Kiesecker et al.[44] estimated that over 3.1 million ha of KBAs and ranges of 1,574 threatened and endanger species could be impacted. This research underlines the importance of strategic planning and early risk screening to avoid sensitive biodiversity areas (Section 3). For further guidance, see IUCN and partner guidelines on managing development risks within KBAs.[45]

These are usually developed by government agencies, sometimes working with development banks, including through Strategic Environmental Assessments that identify suitable areas for development with biodiversity as a consideration (Section 3.2). Given the potentially large energy contribution and space requirements of renewable technologies (Section 1), such a proactive strategic spatial assessment is important to avoid undermining biodiversity conservation goals.

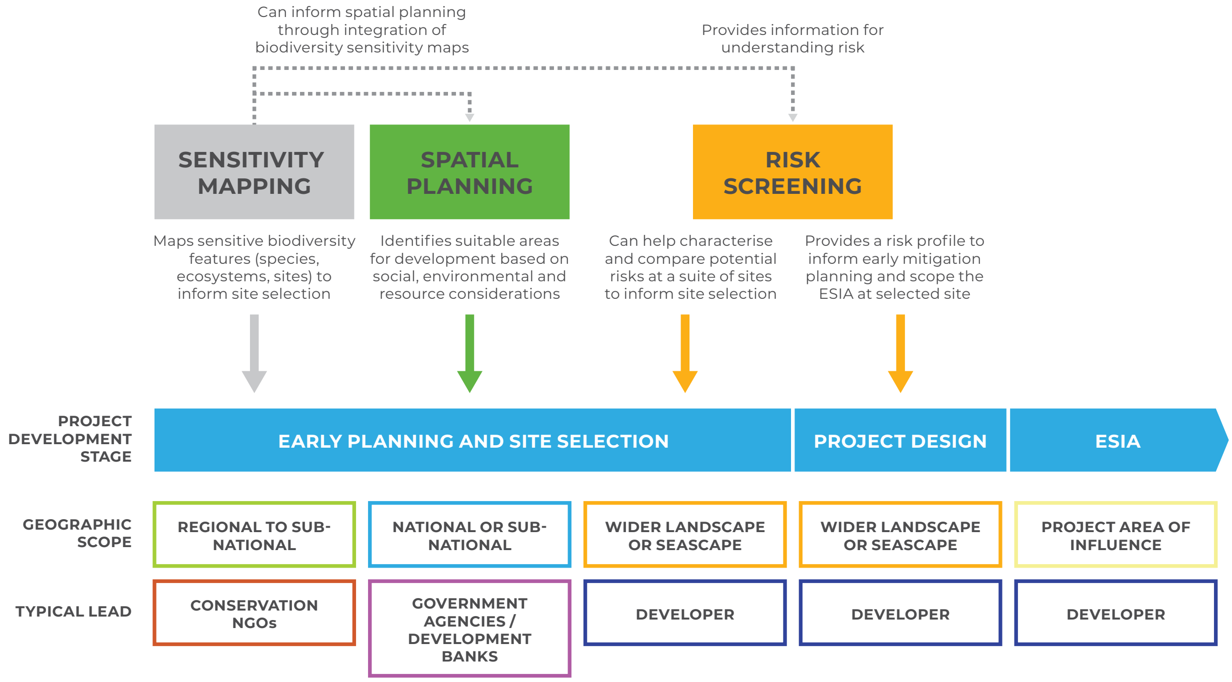
Figure 3.1 Early planning in the project life cycle and implementation of mitigation hierarchy



Note: Avoidance through early planning can be informed by spatial planning and/or sensitivity mapping, where available, to identify suitable areas for development. Early risk screening further helps identify avoidance opportunities at one or more potential sites. Potential requirements for offsets to address residual impacts also need to be considered early in the project design stage (Section 7).

41 IUCN (2016).
42 IUCN (2016).
43 Rehbein et al. (2020).
44 Kiesecker et al. (2019).
45 The KBA Partnership (2018).

Figure 3.2 Spatial planning, sensitivity mapping and risk screening in the early planning process



Note: Outputs from sensitivity mapping and spatial planning help developers identify suitable areas for development as part of early planning and site selection. Spatial planning may be informed by, or a component of, Strategic Environmental Assessment (see section 3.2). Early risk screening then provides an effective tool to compare potential sites. Risk screening is also useful as part of project design, to help identify early mitigation options at the selected site and scope the ESIA to focus on key risks.

In the absence of specific guidance from policy makers, biodiversity **sensitivity maps** can help identify sites to avoid (Section 3.3). Further **risk screening** can then be undertaken to support site characterisation and help assess biodiversity sensitivities for one or more potential project sites (Section 3.4).

Figure 3.1 illustrates the position of early planning in the project life cycle and implementation of the mitigation hierarchy. Figure 3.2 outlines the broad relationship between spatial planning, sensitivity mapping and risk screening in the early planning process. Figure 3.3 shows the three processes in relation to their geographic scope. Figure 3.4 outlines the process of early planning for avoidance by site selection from a project developer's point of view.

Figure 3.3 Relationship between spatial planning, sensitivity mapping and site selection

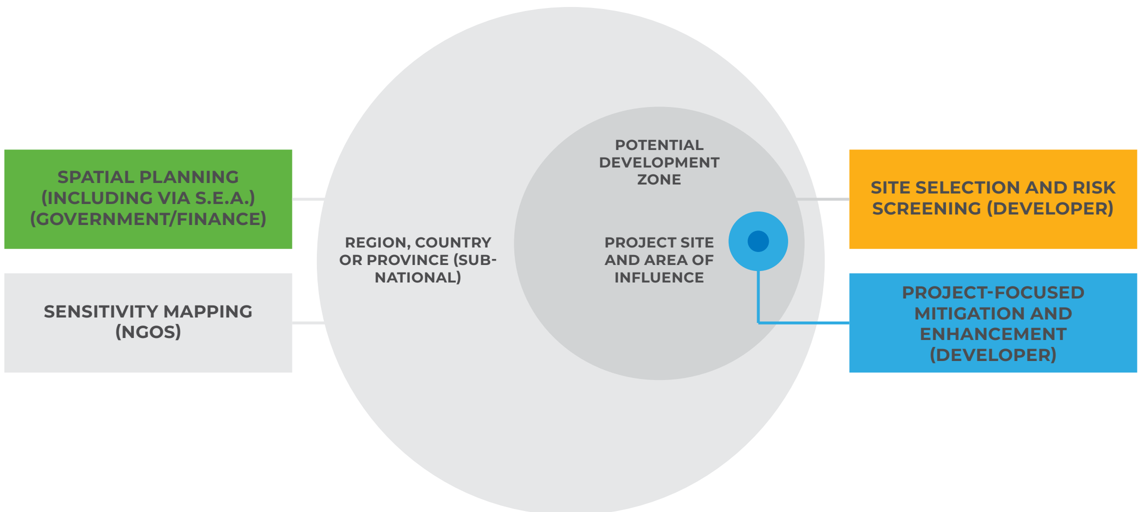
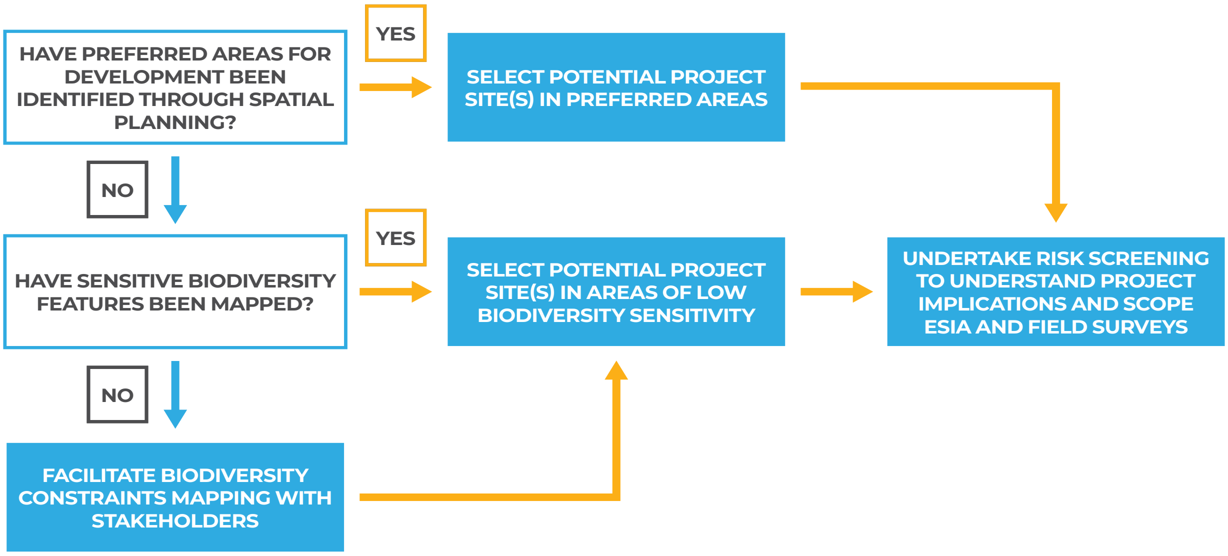


Figure 3.4 Process of early planning for avoidance by site selection from a project developer's perspective



Note: Spatial plans (potentially informed by, or a part of, Strategic Environmental Assessments) may identify preferred areas for development. If no spatial planning has been carried out, sensitivity maps may be available to inform avoidance of sensitive biodiversity. In the absence of such planning exercises, developers may need to use existing biodiversity information and work with stakeholders to map potential project site(s) in areas of low biodiversity sensitivity. Further site-level risk screening is then needed to identify biodiversity risks, understand project implications and help scope the ESIA.

3.2 Spatial planning and Strategic Environmental Assessment

Avoidance by site selection should ideally be guided by area-based planning that integrates biodiversity considerations into renewable energy siting decisions (Annex 2, Box 5), thus identifying preferred zones for development. There are well-established processes for marine spatial planning[46] and land use planning,[47] but many places still lack such plans, and existing plans may not consider wind and solar energy.

Land use and marine planning can be informed by Strategic Environmental Assessment (SEA),[48] a process that evaluates the environmental effects of plans, programmes and policies at the regional, national or sub-national level. SEAs aim to identify the environmental consequences of anticipated development (for one, or ideally across different several sectors), so that these can be fully accounted for and appropriately addressed alongside economic and social considerations. The objective is to make the overall outcomes of policies, plans and programmes as positive as possible.

SEAs generally follow steps defined within a regulatory framework, but scope and approach vary considerably between jurisdictions and between individual SEAs. SEAs can provide an input to broader, integrated spatial planning.[49] However, they often already combine environmental information, including sensitivity maps (Section 3.3), with resource, economic and social considerations. Some SEAs themselves determine favoured areas within which regulatory approval may be simplified or fast-tracked, and appropriate site(s) can be identified. They may also identify sensitive areas that are out of bounds for development, sometimes called 'no go' areas, which might include formal Protected Areas or Internationally Recognised Areas (Box

46 An integrated, policy-based approach to the regulation, management and protection of the marine environment, including the allocation of space that addresses the multiple, cumulative and potentially conflicting uses of the sea and thereby facilitates sustainable development. See Jay (2017) and MSPP Consortium (2006).

47 Metternicht (2017).

48 SEAs are distinct in objectives and process from Environmental Impact Assessment applied at project level.

49 Annandale (2014).

7, Annex 2, case study 10). SEAs often also assess potential cumulative impacts of multiple developments and their significance (Box 6).

SEAs are typically led by government agencies as part of regulatory processes, as in South Africa's SEA for wind and solar photovoltaic energy[50] (Annex 2, case study 15). They may also be led or supported by development banks or agencies to inform their own and/or government decisions). SEAs are increasingly recognised as an important tool to inform development at the national or sub-national level (Annex 2, case study 8).[51]

Where spatial plans identify preferred development zones, this provides project developers with a clear framework and level playing field within which to operate. Developments in preferred zones may also be subject to faster or less stringent permitting processes. Zoning can help developers:

- Reduce risks and costs related to regulatory approval, including lengthy ESIA processes;
- Minimise investment risk and speed up permitting;
- Provide access to finance;
- Reduce uncertainty concerning biodiversity risks and mitigation options;
- Reduce the need for detailed scoping surveys and assessments, including sensitivity mapping;
- Help avoid conflict with conservation stakeholders; and
- Reduce (or ideally avoid) liabilities associated with implementing offsets.

Spatial plans do not eliminate the need for further risk assessment and avoidance of sensitive areas at the site level, even within identified development zones. Further consultation with stakeholders is also needed, for example, to identify local biodiversity priorities, which may not have been considered in national-level assessment.

Box 5 Integrated planning to consolidate the climate benefits of renewable energies

Contributed by: Joseph Kiesecker, The Nature Conservancy

Solar and onshore wind energy development have often involved clearing natural lands or fragmenting wildlife habitat[52] and these land-use impacts are projected to increase.[53] In the face of climate change, which is likely to interact strongly with other stressors, wildlife conservation requires proactive adaptation strategies. Maintaining large and intact natural habitats, and maintaining or improving the permeability of land for the movement of both individuals and ecological processes, may provide the best opportunity for species and ecological systems to adapt to changing climate.[54] Avoiding impacts to undisturbed areas will be critical,[55] which means guiding renewable energy development toward areas with existing footprints will be important. Renewable energy's potential benefits to biodiversity from climate change mitigation will be realised only if development can avoid and mitigate impacts to remaining habitat.[56]

50 DEA & CSIR (2019).

51 Nearly a quarter (24%) of the parties to the Convention on the Conservation of Migratory Species of Wild Animals recently mentioned conducting SEA for plans or programmes within the renewable energy sector Convention on Migratory Species (CMS) (2020).

52 Kiesecker & Naugle (2017).

53 Kiesecker et al. (2019).

54 Anderson & Ferree (2010).

55 Mawdsley et al. (2009).

56 Kiesecker et al. (2019); Kiesecker & Naugle (2017).

The development of renewable energy 'go zones', or landscape zoning, can be an effective way to drive renewable energy and related transmission to low-impact areas (Annex 2, case studies 8, 15, 25 and 31). Renewable energy zones, with fast-tracked project approval, need to have high-quality renewable energy resources, suitable topography and land use designations. Fast-tracking the project identification of areas must also integrate environmental and social considerations. When renewable energy expansion is constrained by a lack of existing transmission, zoning for transmission is also key. Recent work in the Mojave Desert, California, explored the concept of landscape zoning to design solutions that are low cost, low carbon and low conflict by integrating spatially explicit data on areas important for biodiversity conservation. Here, the U.S. Bureau of Land Management (BLM) mapped the most biologically diverse, unspoiled places to help identify 570,000 hectares that are well-suited for solar development. In 2015, BLM adopted the plan, aligned with the assessment that identifies 19 solar energy zones in six states and designated large areas as off-limits for development. So far, three projects totalling 480 MW (enough to power roughly 100,000 homes) have been approved in less than half the previous average permitting time.[57]

Integrating landscape zoning into the energy planning process also provides opportunities to influence the energy mix and the potential environmental impacts of the renewable energy transition. This involves evaluating the environmental and system cost implications of siting policies and energy procurement standards. Currently, renewable energy planning relies on electricity capacity expansion models, which simulate future investments in generation and transmission infrastructure given assumptions about energy demand, technology costs and performance, resource availability, and policies or regulations (e.g. GHG emissions targets). Often conducted at the national or sub-national jurisdictional level, capacity expansion models typically determine targets for particular energy types before decisions on individual projects are made. However, these models often fail to account for environmental values. Recent work by The Nature Conservancy looked at pathways to meet California's 100% zero-carbon electricity policy. Using capacity expansion models and detailed spatial datasets representing ecological, cultural and agricultural siting criteria, the study shows that there are multiple pathways to achieving this clean energy target while avoiding significant ecosystem impacts.

To ensure a rapid transition to renewable energy financing needs to be scaled up not just for new renewables but for system planning, via both domestic budgets and support from international financial institutions. The integration of capacity expansion models to guide siting of new renewables has tremendous potential to help decision makers understand trade-offs of different options and identify those options that perform well across a range of objectives.

57 Cameron et al. (2017).

3.3 Sensitivity mapping

Sensitivity (or constraints) mapping is a multi-stakeholder process that maps the recorded or predicted presence of biodiversity features (species, sites and/or ecosystems) considered sensitive because of their importance and/or their susceptibility to impacts. Such features might include, for example, threatened bird species at high risk of collision with wind turbines, protected areas[58] or other areas of high biodiversity significance designated at regional and international levels, such as Important Marine Mammal Areas (IMMAs) and Key Biodiversity Areas and (Box 7 and Annex 2, case study 2). Sensitivity mapping can be combined with information on wind and solar resources as well as economic and/or social constraints to support identification of appropriate sites for development. Sensitivity mapping synthesises and analyses of existing information to highlight areas sensitive for biodiversity that are best avoided by renewable energy developments. Sensitivity mapping is particularly relevant in the absence of other spatial planning such as through a government-led SEA.

To date, sensitivity mapping has typically been NGO-led, although there is a growing recognition that governments need to integrate sensitivity mapping as part of their development planning processes. Developers often help facilitate or support the process to inform site selection. Finance, government and community stakeholders may also be closely involved (Annex 2, case study 10 and 33). To identify important features and assess their susceptibility, consultation with a range of stakeholders, including both biodiversity and social specialists, is key (Section 3.5 on working with stakeholders), as is a well-defined process for the mapping exercise (Annex 2, case study 33).

Sensitivity mapping can help developers:

- Identify appropriate project site options, including no-go areas, as part of risk screening (Section 3.4);
- Reduce potential conflict with conservation stakeholders;
- Reduce risks related to regulatory approval and access to finance; and
- Reduce assessment and mitigation costs.

Developers need to consider limitations to using these outputs, which include potential data gaps (areas may be mapped as seemingly lower risk because of limited data) and adequacy of the data (national maps may not be appropriate for informing site selection at finer scale). It is also important to consider additional priorities for aligning with regulatory and/or finance requirements that may not be included in sensitivity maps.

Following development of sensitivity maps, biodiversity risk screening can help identify site-specific sensitivities and scope the ESIA and field surveys (Section 3.4).

58 Including World Heritage Sites. Sensitivity mapping for World Heritage Sites should take into consideration the Outstanding Universal Values of the sites and attributes that convey these.

Box 6 Cumulative impact assessment

Cumulative impacts result from the "successive, incremental, and/or combined effects [of a development] when added to other existing, planned, and/or reasonably anticipated future ones".[59] There are several reasons why it is important to consider cumulative impacts, and not just the separate impacts of each individual development:

- Impacts that are considered minor at individual project level can add up to cause a significant effect;
- Impacts of different developments may interact, which may not be obvious without analysis;
- Assessment across projects and/or sectors may improve the planning and effectiveness of mitigation, showing up opportunities for co-ordination and collective action; and
- The project's own mitigation efforts could be affected by impacts from other developments.

Cumulative impact assessment (CIA) may be confined to one sector (e.g. looking at the impacts from a suite of wind power projects) or may look across the board at pressures from many sectors and sources (sometimes referred to as aggregated or in-combination impacts).

Solar and wind energy projects often concentrate in particular areas where there is good resource, creating potential for cumulative impacts. These projects also often interact with highly mobile, wide-ranging species, including migratory birds, bats, terrestrial mammals, cetaceans and/or fish, that may encounter many developments during their extensive movements. Linear infrastructure constructed to support renewable projects, such as transmission lines and roads, can create collision risks and barrier effects, which also need to be considered for cumulative effects.

Since individual developers have limited potential to influence impacts beyond their project, mitigation of cumulative impacts is best addressed at the regional or national level through wider strategic planning. Developers or industry consortiums may make input to such processes, but do not usually lead them. Nevertheless, many regulators and financers (including the IFC) require developers to account for cumulative impacts in project ESIAs and mitigation plans. Failure to address cumulative effects has led to permitting rejections for projects. For example, in the United States in 2015, a federal judge in Nevada revoked an approval for the state's largest wind power project as it did not properly evaluate potential cumulative impacts to golden eagles (*Aquila chrysaetos*) and Mojave Desert tortoises (*Gopherus agassizii*).[60]

The early planning process thus needs to account not only for project-specific impacts, but also consider the project's contribution to cumulative impacts and adapt the location and design to ensure it does not lead to long-term population declines for priority species. Population-level impacts (Sections 4.2.3, 5.2.3, 6.2.3) can be assessed through various approaches, which may include modelling. Where data are limited, assessment of potential biological removal provides an estimate of the threshold beyond which cumulative losses may cause population declines. However, this is sensitive to the assumptions applied and not appropriate where populations are declining or do not show density-dependent recovery.[61] Where there are multiple projects in an area, there is scope for developers to share costs through joint planning and implementation of surveys and assessments.

59 IFC (2013).

60 Streater (2015).

61 Cook & Masden (2019) and Schippers et al. (2020) propose an alternative formulation for cumulative impact thresholds, based on the species' population growth rate at low density and the acceptable population response.

Specific approaches to CIAs will differ depending on the project and biodiversity context. IFC's guidance outlines how to undertake the 'rapid CIA' assessment that is likely to be required of project developers when there are concerns about potential cumulative impacts.[62] This is not a full-scale CIA but a (usually) desktop exercise that aims to identify where the project's impacts might, when combined with others, put the sustainability of a biodiversity feature at risk; and the management measures needed to mitigate for this.

A rapid CIA typically includes the following steps:

- Identify priority social and environmental valued environmental components (VECs) for assessment. For biodiversity, this may include species or ecosystems vulnerable to cumulative impacts, as well as reflecting stakeholder values and concerns related to biodiversity and ecosystem services. The focus should be on those where the project is most likely to make a significant contribution to cumulative impacts.
- Identify the appropriate spatial and temporal scope for assessment. Geographic scope is determined on an ecological basis, and considering the distribution of impacts, and so is likely to extend much more widely than the project's direct area of influence, covering all habitats for a species in the region or a species' migration pathway. The temporal scope should at minimum cover the period over which the project's impacts will occur.
- Engage with stakeholders and specialists to compile and map available information on the priority biodiversity features and current/planned development infrastructure.
- Assess current baseline conditions and future trends of priority VECs based on currently available data and specialist interpretation. Field surveys may be undertaken to address significant gaps, but this is usually not needed for a rapid CIA.
- Establish cumulative impact estimates and thresholds beyond which losses would risk long-term viability of species populations, or ecosystem integrity.
- Assess the significance of potential cumulative impacts, and the project's contribution to these.
- Design appropriate measures to mitigate the project's contribution to significant cumulative impacts. If necessary, identify the potential, or need for, additional mitigation of other existing or anticipated future projects. As far as possible, work with other stakeholders, including other developers, to undertake collaborative management actions such as clustering grid connections from multiple wind farms rather than a point-to-point grid for each wind farm. Effective management of cumulative impacts may require action across national borders, which is often challenging and likely beyond the capacity of individual developers, though there may be opportunities to engage as businesses in international forums and agreements (Section 2.6).
- Undertake ongoing monitoring of effectiveness of mitigation options to ensure long-term viability of priority VECs.

62 International Finance Corporation (IFC) (2013) provides detailed good practice guidance on assessing and mitigating cumulative impacts. Appendix 3 outlines terms of reference for a rapid CIA.

Box 7 Renewable energy development within protected areas

Renewable energy developments that are incompatible with the objectives or the conservation outcomes of a protected or conserved area (for example, as they cause environmental and/or social damage) should be avoided, unless these can be mitigated to the point of not having any residual impacts. This includes developments that are located outside of a protected area, the impacts of which may reach the conservation values within that area, for example, where development of a wind farm could impact a threatened population of raptors residing in the protected area.

The use of biodiversity offsets to address residual impacts within protected areas is considered incompatible with the area's management objectives. For the Outstanding Universal Value, which is recognised in World Heritage Sites, there is by definition no opportunity to offset such impacts.

Most industrial scale activities are therefore incompatible in protected areas, as the likelihood of their impacts on the objectives of the protected area would be very high. Small- and micro-scale developments may be acceptable under certain conditions, for example solar power systems that are needed to meet the energy needs of the protected area, such as powering electric fencing, visitor centres or parking (thus also preventing the need for larger scale energy infrastructure).

Therefore, the approach should be commensurate with the following scale of activities and associated biodiversity risks:

- Large-scale, industrial renewable developments likely to have impacts that cannot be fully mitigated: such development should in all circumstances considered a 'no go'.
- Intermediate, non-industrial scale: developments, serving local needs: assess on a case-by-case basis through rigorous ESIA, and early and comprehensive consideration of site alternatives. Approvals would be subject to clear demonstration of effective mitigation to reduce any impacts to non-significant levels, and a comprehensive monitoring and evaluation plan.
- Micro to small scale, serving local needs: assess on a case-by-case basis.

For World Heritage sites, given their globally significant value, only micro to small scale could be considered compatible, subject to a case-by-case assessment.

In all cases, developers must work closely with national, local and other relevant authorities to assess the legality and feasibility of operating within or close to a protected area or a conserved area.

These recommendations build on IUCN Resolutions and Recommendations and, in particular, on WCC-2016-Res-059-EN IUCN Policy on Biodiversity Offsets and on WCC-2016-Rec-102-EN Protected areas and other areas important for biodiversity in relation to environmentally damaging industrial activities and infrastructure development.

3.4 Risk screening

3.4.1. About risk screening

Biodiversity risk screening is a desk-based exercise that provides a risk profile to inform early mitigation planning and ESIA scoping as part of project design. Screening can also help inform site characterisation and compare potential risks at a suite of sites as part of site selection (Figure 3.2). It can also help developers understand the implications for aligning with financing safeguards, inform mitigation planning as part of project design, and help scope the ESIA and further field surveys (Figure 3.5).

Risk screening is led by developers with input from biodiversity and other specialists. Typically, it is desk-based and uses global biodiversity datasets with specialist interpretation.

Screening outputs usually comprise a list of priority biodiversity features – species, ecosystems and sites – that are of particular sensitivity, such as areas potentially sensitive to development defined under IFC PS6 as 'Critical Habitat', supported by maps that help identify areas of high biodiversity and ecosystem services sensitivity. Table 3-1 provides a summary of key information needs and outputs from risks screening for different types of risk associated with solar and wind developments. Annex 3 provides a list of species groups that are known to be particularly sensitive to solar and wind developments.

Figure 3.5 Key questions for risk screening

EARLY PLANNING	- What is the overall biodiversity sensitivity of the area (e.g. presence of Key Biodiversity Areas, protected areas, Critical Habitat)? - What sensitive biodiversity features are likely to be present, including seasonal breeding and feeding area and important migratory routes? - Are there opportunities to site the project in modified habitats or (re-)develop existing sites? - Are there likely to be residual impacts that require offsets? - What provisioning services are likely to be of importance to local beneficiaries? - Are there potentially important cultural, tourism or social values associated with natural features in the area?
PROJECT DESIGN	- It is feasible to achieve project goals for biodiversity and ecosystem services, such as no net loss or net gain? - What are the types of mitigation and monitoring actions that may be needed, and what are the potential resource requirements? - Is the proposed development likely to be sustainable in this location, given its natural resource dependencies? - What are the further field survey requirements, including species and duration? - Is there a risk of irreversible or non-offsettable impacts? - What are the key stakeholders that the project may need to engage with, including government, NGOs, communities, academia and other environmental and social specialists? - Can the project align with national legislative requirements and financing safeguards? - Are there opportunities to align with national development and environmental and social targets and priorities?
ESIA	- Are there less-damaging alternatives that are feasible? - Are there opportunities to use existing linear infrastructure such as by upgrading roads and transmission lines? - Is it feasible to fully mitigate impacts at the site and avoid the need for offsets? - What are the potential cumulative impacts as a result of the project in combination with other existing/planned developments? - Can project impacts potentially be restored?

Note: Risk screening provides developers with a valuable tool to support site selection and informing project design, including early mitigation opportunities, with a focus on avoidance. The degree to which these questions can be answered will depend on the availability of information at the time of desk-based screening.

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Early risk screening can help developers:

- Save significant time and resources later by enabling identification and avoidance of the most serious risks early on;
- Focus the baseline surveys and ESIA on identifying and addressing key risks;
- Understand and align with finance safeguards and legislative requirements; and
- Demonstrate diligence and commitment towards biodiversity risk management, helping to reassure developers and finance lenders.

While typically used for project planning, risk screenings can also be applied to operational projects to inform decisions around project acquisition or existing assets (as part of repowering) or to evaluate liabilities and requirements in accordance with company, investor or legislative requirements.[63]

As desk-based screening relies on existing information to identify potential biodiversity and ecosystem services risks, its value may be limited in places where relevant data are scarce. Notably, offshore marine areas are often relatively under-sampled and may have limited, unreliable or no information related to the presence or seasonal migration patterns of species. Reliable biodiversity data may also be lacking or absent in some emerging economies with areas of high biodiversity significance. Thus, interpretation of risk screenings must carefully consider such limitations.

Risk screening should inform an ESIA, rather than replace it. Further field surveys and engagement with biodiversity and social specialists will be needed to confirm the status of biodiversity and ecosystem services and inform project decisions. For example, a screening may flag potential presence of a highly threatened amphibian species in the area, based on overlap with its known range. Targeted field surveys may show that the species is unlikely to be present as the area does not support the specific wetland habitat it requires. Conversely, field surveys may identify sensitive species that were not flagged during the desk-based screening.

3.4.2. Approaches and tools

Risk screening uses the best available data to assess biodiversity and ecosystem services risks within an area (or several areas) of interest. Relevant data may cover species, ecosystems, KBAs, protected areas and other areas designated for their biodiversity significance.[64]

Globally available datasets usually provide the main basis for screening, but regional or national data and expert knowledge may also need to be identified and included in the assessment. Typically, field surveys are not carried out in early screening but as a follow-up step to address any significant data gaps and better understand the potential risks identified. However, in some cases, brief reconnaissance visits to site(s) may be valuable for screening.

The general approach to risk screening is presented in Figure 3.6.

A range of biodiversity information platforms can provide spatial data to inform risk screenings (see Annex 1 for a complete list, including regional and national data platforms and tools). Particularly relevant screening tools for renewable energy projects include:

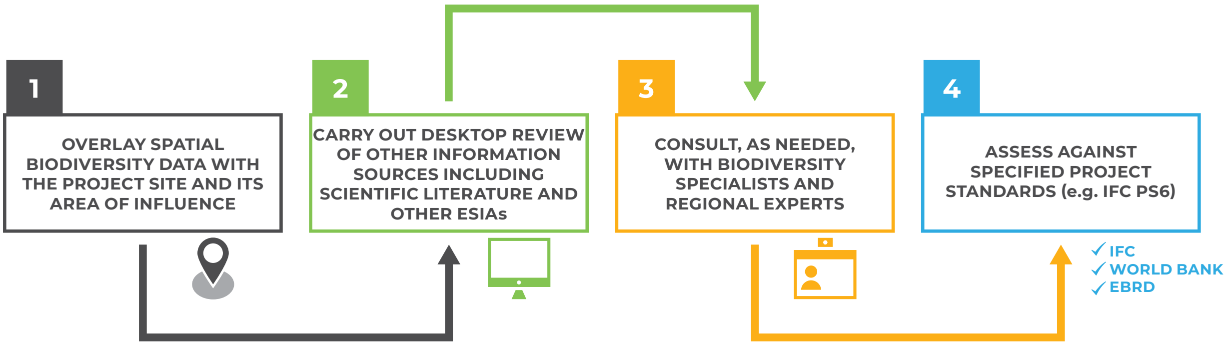
- Integrated Biodiversity Assessment Tool (IBAT): provides subscribers with spatial data for global biodiversity from several key datasets, such as: the IUCN Red List, the World Database on Protected Areas (also see last bullet)[65] and the World Database of Key Biodiversity Areas (which includes Important Bird Areas);
- The Ocean Data Viewer: provides global marine biodiversity and ecosystem services layers;
- The Important Marine Mammal Areas (IMMA) e-Atlas: maps areas of importance for marine mammals globally;
- The Global Biodiversity Information Facility (GBIF): an international network and research infrastructure providing free access to biodiversity data. This platform provides species distribution datasets for all types of terrestrial

63 See TBC (2017) for more information on biodiversity risk screening.

64 These include World Heritage Sites, UNESCO Man and the Biosphere Reserves, and wetlands designated under the Ramsar Convention on Wetlands of International Importance.

65 Further engagement with national stakeholders may be needed to identify protected areas not included on the global database.

Figure 3.6 Generalised approach to risk screening. A risk screening uses available biodiversity data and, through specialist interpretation, develops a profile of project risks and opportunities in the area of interest



and aquatic species, including Movebank, a database that tracks species movements around the globe;

- The Soaring Bird Sensitivity Map tool: provides developers and planning authorities with information on the distribution of soaring bird species along the Rift Valley/Red Sea flyway. This information can be used to identify areas of lower biodiversity sensitivity and risks;
- The Critical Sites Network Tool: provides information on the sites critical for nearly 300 species of waterbirds and the important sites upon which they depend in Africa and Western Eurasia;
- The Protected Planet database: provides a centralised location from which to access the World Database on Protected Areas (WDPA), World Database on OECMs, Global Database on Protected Area Management Effectiveness (GD-PAME) and associated information.

Table 3-1 Examples of key risks and information to consider in risk screening

Key risks	Examples of information			Screening outputs
	Solar	Onshore wind	Offshore wind	
Protected areas and internationally recognised areas of biodiversity significance	Spatial data from national and global databases (e.g. World Database on Protected Areas and Indigenous and Community Conserved Areas (ICCA)) Information on World Heritage policy positions from WH Policy Compendium and WH Committee Decisions Database			Map delineating internationally recognised areas such as Key Biodiversity Areas
Threatened ecosystems and areas of natural habitat in wider landscape or seascape	Spatial data and status of sensitive terrestrial ecosystems including wetlands, forests, rivers and other types of natural habitat Presence of modified landscapes to inform project placement to avoid natural habitat		Spatial data and status of sensitive benthic ecosystems (coral reefs, seagrass, mussel beds, etc.) Abiotic factors, such as depth, salinity, temperature, that can serve as a proxy for identifying sensitive habitats	Habitat maps of wider landscape/ seascape

Threatened species and particularly vulnerable species (those at perceived high collision risk)	Presence of waterbirds, insectivorous bats, insects (attraction of insects to panels) and species with a highly restricted range Presence of species congregations such as at bat roosting sites, bird colonies, etc.	Locations of bat roosting sites and bird nesting, roosting and feeding sites Species-specific information on flight behaviour, foraging distances and routes for vulnerable birds (e.g. large soaring birds, raptors, etc.) and bats Presence of landscape features associated with collision-vulnerable species such as high-relief features (such as cliff edges, ridges) for raptors and linear features (e.g. rivers and forest edges) for bats Species migration or frequently-used routes including locations of migratory bottlenecks	Presence of marine mammals and seabirds, including feeding and breeding congregations (seabird colonies) Species-specific information on flight behaviour, foraging distances and routes for vulnerable seabirds and bats Presence and activity of marine mammal and fish species vulnerable to noise and disturbance Species migration or frequently-used routes including locations of migratory bottlenecks such as narrow straights used by birds to cross bodies of water	List of species including information on threat status, range, habitat association, behaviour, etc. Maps of wider landscape/ seascape identifying species congregations and delineating bird foraging distances and migratory routes including locations of migratory bottlenecks
Ecosystem service dependencies, use and values	Areas important for provisioning services, such as forest products, farming, hunting, etc. Presence of cultural, tourism or social values associated with natural features in area Information on local water use and water stress levels	Areas important for provisioning services, such as forest products, farming, hunting, etc. Presence of cultural, tourism or social values associated with natural features in area	Areas important for provisioning services such as fisheries Presence of cultural, tourism or social values associated with natural features in area	Map identifying potentially dependent communities and locations of potential resource dependencies
Potential for cumulative impacts	Project requirements for associated infrastructure such as transmission lines Existing and planned infrastructure in wider landscape (particularly other solar or wind farms) Existing sensitivity maps for region		Project requirements for associated infrastructure such as undersea cables Existing and planned infrastructure in wider seascape (particularly other wind farms) Existing sensitivity maps for region	Map of existing and currently planned project and other infrastructure within wider landscape/ seascape

3.5 Environmental and Social Impact Assessment

Environmental and Social Impact Assessment[66] (ESIA) is a key regulatory requirement for most wind and solar projects. ESIA is a process for predicting and assessing the potential environmental and social impacts of a proposed project, evaluating alternatives and designing appropriate mitigation, management and monitoring measures (Section 8 on monitoring and Section 9 on processes for aligning with good practice). As ESIAs are typically undertaken after a development site has been identified, sensitivity mapping and risk screening are often critical to informing effective early avoidance through site selection.

Risk screening outputs also help to focus the ESIA by informing the scoping of baseline studies and design alternatives (Figure 3.2). Close and early collaboration between environmental/social specialists and project engineers, from the risk screening stage onwards, can help identify effective avoidance and minimisation measures through design and scheduling alternatives. Engagement with suppliers of construction materials is needed to evaluate and address potential biodiversity impacts along the supply chain (Section 10 on supply chain stewardship).

Early engagement is also needed with community, government and civil society stakeholders (Section 3.6) to identify and validate appropriate locations, impacts, mitigation measures, including the feasibility of offsets if all impacts cannot be avoided, minimised and restored. External engineering and procurement contractors may also need to be brought into the ESIA process at an early stage to confirm the feasibility of mitigation measures, and in due course to bring these into contractual agreements.

3.6 Working with stakeholders

Constructive engagement with stakeholders, especially the diverse rights holders, is vital for helping to identify and effectively manage biodiversity risks. Having a structured approach to stakeholder engagement is considered good environmental practice by various governance standards including the IFC Performance Standards, the OECD Guideline for Multinational Enterprises and the UN Global Compact. Stakeholder involvement should guide a developer in identifying risks and confirm the feasibility of mitigation measures, as well as prove the opportunity to raise any concerns.

Stakeholder engagement is rarely a straightforward or simple process. It requires a degree of up-front effort and helps lay the foundation for constructive relationships and for creating shared values (Box 8). Where adequately integrated into early project planning, it can save significant time and resources later on with issues, such as permitting delays, protests, complaints and lawsuits.[67]

A first step is to identify the appropriate level and type of engagement with stakeholders through a mapping exercise. This should take place as part of early planning, and inform the development of a stakeholder engagement plan. A wide variety of potential stakeholders may be of importance, depending on the nature of the company or project (Annex 2, case study 11). Biodiversity-relevant stakeholders typically include the following: national government, intergovernmental agencies and organisations; national and international environmental NGOs; biodiversity specialists; local communities, including the diverse rights holders, indigenous peoples (Box 9) and natural resource users; financial institutions; and universities or research institutions, including IUCN Specialist Groups (Annex 2, case studies 29 and 33).

66 Often referred to as Environmental Impact Assessment (EIA).

67 Pollard & Bennun (2016).

Box 8 Creating shared value

Proactive and authentic engagement with local stakeholders can help developers identify new business opportunities that simultaneously advance the economic and social conditions in the communities in which it operates. This approach is commonly referred to as Creating Shared Value and is gaining traction with an increasing number of businesses. It provides opportunities for renewable developments to go beyond the regulatory requirements to develop a strategy that provides opportunities to business whilst meeting local needs. For example, solar energy projects can significantly improve local energy access within emerging markets through community solar projects delivered through innovative public-private partnerships. Such an approach can provide companies with a social license to operate but also reduce costs, develop new business models, and provide a mutually beneficial basis to ensure long-term business sustainability.

After stakeholder identification, communication and effective engagement with the identified stakeholders follows and continues throughout the project lifecycle. Early disclosure and regular reporting help majority stakeholders understand the project risks, impacts and opportunities, to jointly produce appropriate solutions. To maintain a constructive relationship, it is important for stakeholder engagement to move beyond mere process and actively engage in shaping the development, implementation and stewardship of the natural resources as well as their participation in the decision-making process. Those views may be diverse, so project responses may often need to be carefully considered and explained. Establishment of grievance mechanisms may be set up to provide stakeholders with the opportunity to raise concerns which were considered to not have been adequately dealt with through the consultation process.

Effective stakeholder engagement requires commitment of capacity and resources from the project, as well as a willingness to listen, learn and adapt. It can provide multiple opportunities, which can potentially mitigate impacts and manage risks to the company (Annex 2, case study 14). Developing transparent and constructive relationships with stakeholders can help:

- Identify priority biodiversity features and ecosystem services for consideration during early screening, impact assessment and mitigation planning;
- Understand the status of important biodiversity features, including their value to local stakeholders (as part of baseline studies);
- Enhance transparency and improve reputation, and thus the social license to operate;
- Identify appropriate actions to mitigate impacts on biodiversity including conservation goals (e.g. through systematic conservation planning); and
- Build partnerships for implementation of mitigation actions, including offsets.

Further guidance on effective stakeholder engagement is provided in Annex 1.

Box 9 Working with Indigenous Peoples

Indigenous peoples and local communities hold and manage a significant part of the Earth's most biodiverse regions and play a vital role in conserving lands, seas and resources. They cultivate an intrinsic and holistic relationship with their natural environments, and have developed and often maintain local and indigenous knowledge systems and management practices that contribute to biodiversity conservation and sustainable use of natural resources.

Developers should consult and cooperate in good faith with indigenous peoples to obtain their Free Prior Informed Consent (FPIC) on any project affecting their lands, territories and resources that are used by these rights holders.

Developers, in conjunction with indigenous peoples, will need to work with the affected communities to identify and secure their: i) sacred or cultural heritage sites and values; and ii) rights to access, use, benefit from natural resources for the guarantee of their subsistence of present and future livelihoods within the project's area of influence. Appropriate actions should be undertaken to avoid or remedy impacts, as well as guarantee the protection of rights of access to such sites or values. Where indigenous peoples' sacred or cultural heritage sites and values may be impacted, developers will need to seek FPIC from indigenous peoples.

In support of the rights of indigenous peoples, the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) is the most comprehensive international instrument on the rights of indigenous peoples. It establishes a universal framework of minimum standards for the survival, dignity and well-being of indigenous peoples of the world and elaborates on existing human rights standards and fundamental freedoms as they apply to the specific situation of indigenous peoples. UNDRIP also calls for the right of FPIC.

Part II

Solar energy
Potential impacts and mitigation approaches

Onshore wind energy
Potential impacts and mitigation approaches

Offshore wind energy
Potential impacts and mitigation approaches

4. Solar energy – Potential impacts and mitigation approaches

4.1 Overview of a solar plant

This chapter presents an overview of the primary biodiversity and ecosystem service impacts of solar energy, followed by discussion of the key mitigation approaches that can be employed at each project stage (design, construction, operation and end-of-life).

There are two main types of solar plants:

i. **Photovoltaic (PV)** plants: use solar (PV) panels to convert light to electrical energy via the photovoltaic effect. PV projects vary substantially in scale, from the residential projects typically installed on the rooftops of individual buildings/ dwellings, to utility-scale projects covering large areas of land. In recent years, floating photovoltaic systems (on water bodies such as reservoirs) have also started to appear (Box 10).

   This section focuses specifically on utility-scale developments.

ii. **Concentrated solar power (CSP)** plants: use concave reflecting surfaces (i.e. concentrating solar collectors) to concentrate sunlight to heat a target area. The heat is used to drive a heat engine, usually a steam turbine, to generate electricity. Several different concentrating solar collector technologies have been developed for CSP, including:

   - Tracking mirror arrays (heliostats) that concentrate reflected light on a fixed centralised receiver ('solar power tower');
   - Parabolic 'solar troughs' that focus light on a receiver running along their focal line;
   - Parabolic dish system comprising standalone parabolic reflectors that concentrate light on a receiver at the focal point; and
   - Arrays of linear mirrors ('Fresnel reflectors') that focus light on liquid-filled tubes.

The primary components common to both PV and CSP plants include (Figure 4.1):

- Electrical infrastructure, such as cabling from solar arrays, transformers, the on-site substation and transmission lines to connect to the power grid;
- Module mounting (or tracking) systems; and
- Security perimeter fence.

CSP plants also include concentrating solar collectors and receivers such as solar power towers.

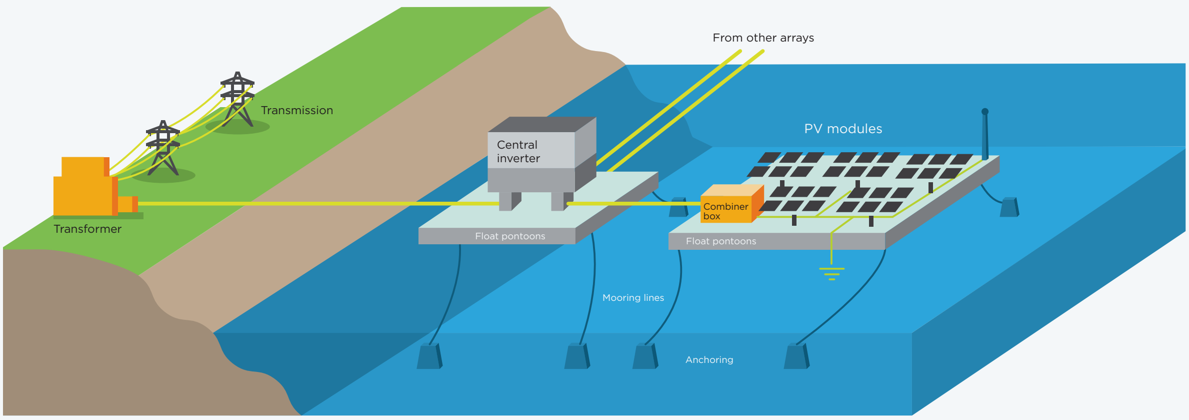
Box 10 Floating solar PV – Status, impacts and mitigation

Floating solar PV technology, sometimes called 'floatovoltaics', is similar to conventional land-based solar plants, except that the PV panels and inverters are installed on a floating platform (Figure 4a). They can be installed on the surface of a pond, lake, reservoir or on any other water body. This technology is fast emerging, with installed capacity globally reached 1.3 gigawatt-peak (GWp) at the end of 2018. Accelerated deployment is expected to occur as the technology matures, but as with any new technology, is faced with a number of engineering challenges hindering widespread deployment.[68]

Benefits of floating solar technology are recognised, such as avoidance of land use competition, increased energy generation and reduced water evaporation.[69] Impacts to onshore biodiversity impacts faced by conventional solar developments are known (Section 4.2). However, little is known of the negative effects of floating solar PV on biodiversity, especially on aquatic ecosystems and water quality. For example, operational floating solar plants blocks sunlight penetration into waterbodies consequently inhibiting algal growth.[70]

Floating solar PV has been presented as a solution to mitigating some negative biodiversity impacts associated with the physical land required for conventional solar plants,[71] if appropriately sited. For example, deployment over artificial water bodies is likely to be preferable to natural systems such as lakes and ponds. Avoidance and minimisation by site selection (Section 4.3.2) is therefore critical to avoiding and minimising the negative impacts of biodiversity.

Figure 4a Floating solar PV



Adapted from SERIS (2019, fig 1.3, p. 13)

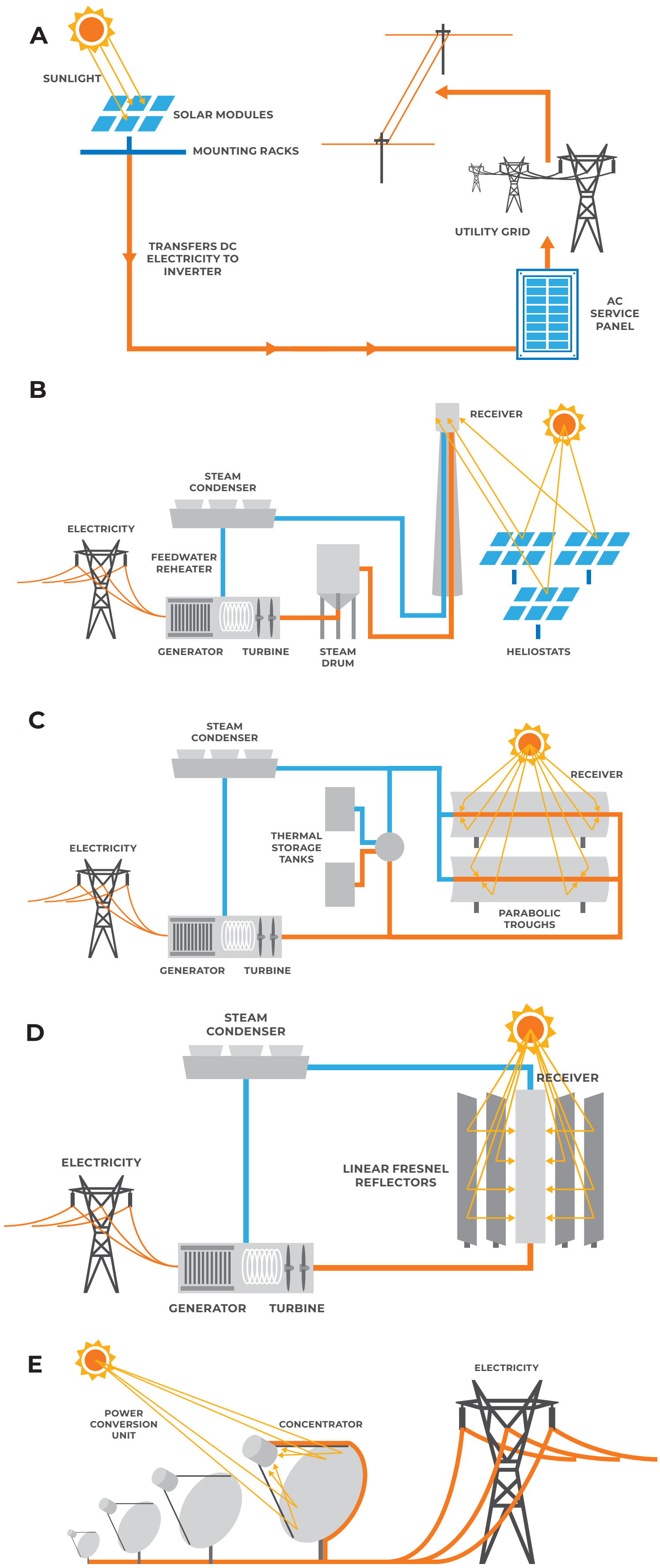
68 IRENA (2019a); Energy Sector Management Assistance Program (2019).

69 Sudhakar (2019); Energy Sector Management Assistance Program (2019).

70 Pimentel Da Silva & Branco (2018); Energy Sector Management Assistance Program (2019).

71 Choi (2014).

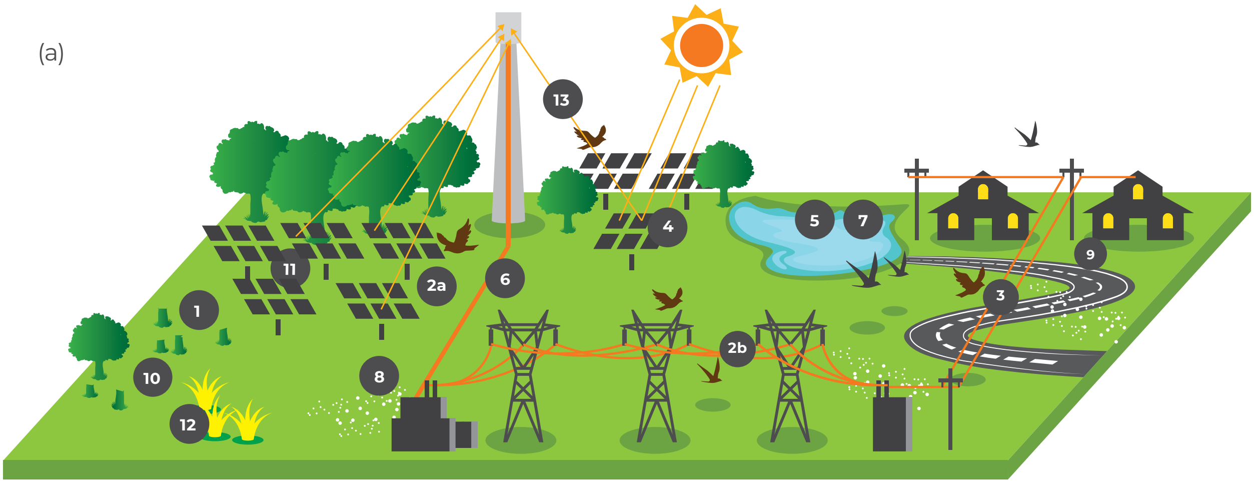
Figure 4.1 Types of solar plants: (A) PV; (B) CSP heliostat; (C) CSP parabolic troughs; (D) CSP parabolic dish; and (E) CSP linear Fresnel reflectors



Source: Adapted from IFC (2015, fig. 2, p. 24).

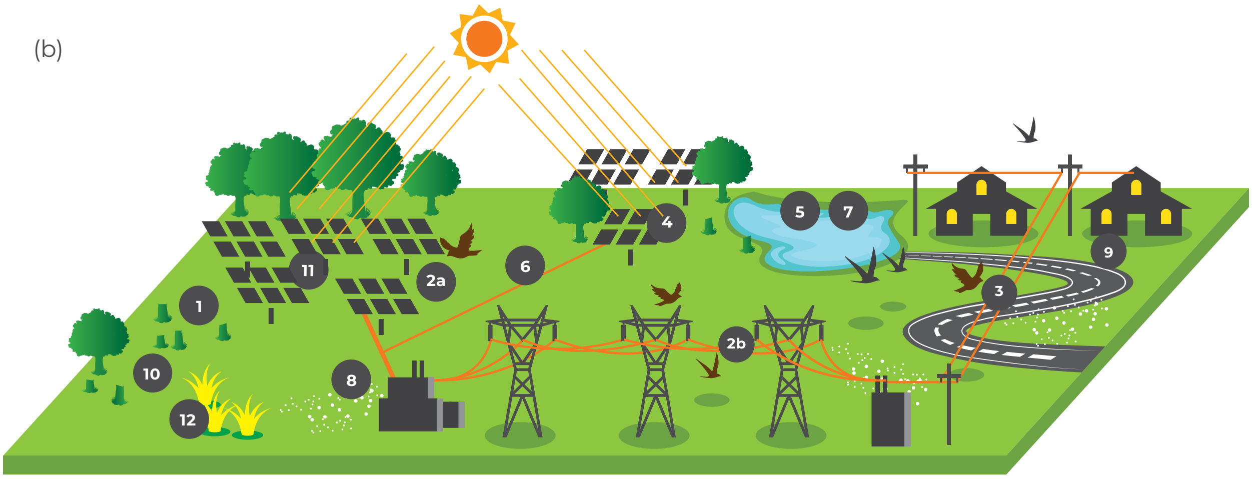
Figure 4.2 Potential impacts on biodiversity and associated ecosystem services associated with (a) CSP and (b) PV. Please see Table 4-1 for details on each impact type

(a)



1. Loss of habitat through clearance or displacement of land
2. Bird collision with (a) solar panels, and (b) transmission lines
3. Bird and bat mortality through electrocution on distribution lines
4. Displacement due to attraction to reflective surface of solar panels
5. Wildlife mortality due to attraction to evaporation ponds
6. Barrier effects to terrestrial biodiversity movement
7. Habitat degradation due to changes in hydrology and water availability and quality
8. Pollution (e.g. dust, light, noise and vibration, solid/liquid waste)
9. Indirect impacts from displaced land-uses, induced access or increased economic activity
10. Associated ecosystem service impacts
11. Habitat alteration due to changes in microclimatic effect of solar panels
12. Introduction of invasive alien species
13. Singeing of birds that fly into path of concentrated light energy

(b)



1. Loss of habitat through clearance or displacement of land
2. Bird collision with (a) solar panels, and (b) transmission lines
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7. Habitat degradation due to changes in hydrology and water availability and quality
8. Pollution (e.g. dust, light, noise and vibration, solid/liquid waste)
9. Indirect impacts from displaced land-uses, induced access or increased economic activity
10. Associated ecosystem service impacts
11. Habitat alteration due to changes in microclimatic effect of solar panels
12. Introduction of alien species

4.2 Impacts of solar energy on biodiversity and ecosystem services

4.2.1. Summary of key impacts

Compared to wind energy developments, there is currently limited scientific evidence of the impacts from solar developments on biodiversity and ecosystem service. From the available literature on biodiversity impacts,[72] the potential biodiversity impacts of PV and CSP are similar but not identical and many are inferred. These impacts are illustrated in Figure 4.2, and summarised in Table 4-1.

Solar plants have been shown to create positive biodiversity impacts when compared to other types of intensive land use. For example, solar plants in the UK previously used for agriculture were found to have a greater diversity of flora and birds when managed through grazing.[73] Section 7.2.1 discusses further the potential positive impacts to biodiversity from enhancement.

Table 4-1 Summary of the key biodiversity and associated ecosystem service impacts of PV and CSP solar plants. The significance of particular potential impacts will be context-specific

No.*	Type of impact	Project stage	Description and examples
1	**Habitat loss through clearance or displacement**	Construction/ operation	Construction of PV and CSP plants and their associated facilities typically requires removal of vegetation and surface grading across large areas of land. This may cause habitat loss, degradation and fragmentation, leading to a reduction in species richness and density as demonstrated by a study on birds.[74] The significance of biodiversity impacts will vary depending on the level of degradation of the previous habitat and the geographic location, and in some circumstances may be positive. For example, in the UK solar plants have been found to support a greater diversity of vegetation, invertebrates and birds than surrounding agricultural or other brownfield land where they are often sited.[75] During operation, vegetation is significantly lost or altered. Solar plants typically require some form of vegetation management under, and in the gaps between solar panel arrays. Unwanted vegetation is sometimes discouraged using herbicides, or by covering the ground with gravel to facilitate facility operations. In other cases, some form of vegetation cover is grown but mowed frequently to keep it short. For example, in western North America, solar developments were estimated to have the largest impacts on shrublands compared to other ecosystem types, resulting in the conversion of between 0.60 to 19.9 million ha of the ecosystem.[76]

72 Examples include Harrison et al. (2016); Northrup & Wittemyer (2013); Taylor et al. (2019); Tsoutsos et al. (2005); Turney & Fthenakis (2011).

73 Montag et al. (2016). Other key references are: BSG Ecology (2014); Beatty et al. (2017); Harrison et al. (2016); Hernandez et al. (2014); Jenkins et al. (2015); Visser et al. (2019).

74 Visser et al. (2019).

75 Montag et al. (2016).

76 Pocewicz et al. (2011).

2	**Bird collisions with solar panels and/or transmission lines**	Operation	Like glass or reflective surfaces on buildings, PV panels and concentrating solar collectors, such as heliostats, could present a collision risk to bird and bat species, especially if the surfaces are vertically oriented and/or reflecting light. The extent and significance of these impacts are largely unknown and limited to a small number of studies. Results from fatality monitoring studies across c.13 years at 10 PV plants in California and Nevada, USA, estimated an average annual fatality of 2.49 birds per MmW per year.[77] Collisions with a PV plant with large continuous arrays (that water birds might mistake for water bodies) in Southern California, USA, resulted in a relatively high number of water bird fatalities.[78] Collisions with the (thin and hard to see) earth wire of transmission lines may lead to significant fatalities for some species such as bustards.[79]
3	**Bird and bat mortality through electrocution on distribution lines**	Operation	Electrocution rates on pylons (or poles) of low- or medium-voltage lines can be high and disproportionately affect some species that use pylons of low-voltage lines as perches when hunting or for nesting. An annual mortality rate of c. 0.7 birds per pole was estimated as a result of electrocution on a distribution line in southern Morocco.[80] Electrocutions may also be partially responsible for the decline of some long-lived species.[81] For example, electrocution of Egyptian Vultures (*Neophron percnopterus*) over a 31-km stretch of powerline in Sudan is thought to have resulted in sufficient deaths to partially explain their population declines.[82] Electrocutions are rarely significant on high-voltage transmission lines. There is limited evidence of risks to bats, although electrocution of large bat species, particularly fruit bats, has been identified as an issue associated with distribution lines.[83]
4	**Displacement due to attraction to reflective surface of solar panels**	Operation	There is anecdotal evidence that birds can mistake the flat surfaces of PV panels for water bodies and attempt to land on them – termed the 'lake-effect' hypothesis.[84] This can risk injury and be detrimental to certain birds that cannot take off without a water body. Aquatic insects can also be attracted to the polarised light reflected by PV panels, and display maladaptive behaviour mistaking the panels for water surfaces.[85]

77 Kosciuch et al. (2020).
78 Kagan et al. (2014). Other key references: Huso et al. (2016); Visser et al. (2019); Walston et al. (2016).
79 Mahood et al. (2017).
80 Godino et al. (2016).
81 Angelov et al. (2013); Sarasola et al. (2020).
82 Angelov et al. (2013).
83 Kundu et al. (2019); O'Shea et al. (2016); Tella et al. (2020).
84 Horváth et al. (2009); Huso et al. (2016).
85 Horváth et al. (2010). Other key references: Harrison et al. (2016); Huso et al. (2016); Taylor et al. (2019).

5	**Wildlife mortality due to attraction to evaporation ponds**	Operation	The wastewater from CSP towers is stored in evaporation ponds to facilitate concentration of chemicals before disposal. These ponds may attract wild animals and pose a risk in terms of poisoning (for example by selenium) and drowning.[86] A four-month study of a 50 MW CSP plan in South Africa identified 37 carcasses in evaporation ponds, of which 21 individuals were assessed to have likely drowned. This included birds (four species), reptiles (one species) and mammals (seven species), including the aardvark (*Orycteropus afer*).[87]
6	**Barrier effects**	Construction/ operation	Large areas of PV panels and their associated facilities can disrupt wildlife movement and/or migrations by acting as a barrier. For example, important stopover sites for migratory birds may be lost due to cumulative impacts from several large PV plants along their flyway.[88] Solar plants typically have security perimeter fencing installed. In some cases, existing ground clearance under fences, gaps in the fence weave, and gates allow small to medium sized mammals to pass. However, such fencing could still pose a barrier to large mammal movement and/or migrations. Although direct evidence of the barrier effect of solar facilities is largely unquantified, the barrier effects related to large scale developments and infrastructure components, such as fencing, has been demonstrated to impact species movement, and reduction of range size.[89]
7	**Habitat degradation due to changes in hydrology and water availability and quality**	Construction/ operation	CSP plants use high amounts of water for cooling the system and washing the mirrors, although the use of manual dry brushing methods can help reduce water usage. CSP and PV may also require large amounts of water for cleaning of dust from panels. This water use could alter the availability of surface and groundwater sources to sustain habitats, such as riparian vegetation, particularly in arid regions. Excessive groundwater withdrawal in the Southwestern United States, unrelated to solar developments, reduced riparian plant density and composition,[90] and contributed to the decline of endangered species such as the Devils Hole pupfish (*Cyprinodon diabolis*).[91] Solar plant construction and operation can also lead to water pollution impacts. For example, operational CSP plants can result in thermal pollution from releasing cooling water into freshwater systems, leading to algal blooms and fish mortality, while employing wet-cooling technologies can lead to a risk of contaminating water bodies with hazardous chemicals, such as cooling system toxicants, antifreeze agents, dust suppressors, rust inhibitors, herbicides and heavy metals.[92]
8	**Pollution (dust, light, noise and vibration, solid/liquid waste)**	Construction/ operation	In general, limited process emissions is generated from operational solar plants other than increased polarised light levels and wastewater as already mentioned. Construction, decommissioning and repowering can lead to dust, waste, noise and light pollution impacts. Examples specific to solar developments are limited, but are widely available for other types of infrastructure development.[93]

86 Jeal et al. (2019); Smit (2012).
87 Jeal et al. (2019).
88 BirdLife International (n.d.).
89 Numerous studies have documented the barrier effects of infrastructure developments. For example, see Wingard et al. (2014); Wyckoff et al. (2018).
90 Webb & Leake (2006).
91 Riggs & Deacon (2002).
92 The Joint Institute for Strategic Energy Analysis (2015).
93 For some examples, see Farmer (1993); McClure et al. (2013); Rahul & Jain (2014).

9	**Indirect impacts**	Construction/ operation	In some cases, land take for solar developments and their associated facilities may displace other land uses such as agriculture). For example, c.150 km^2 of agriculture land was converted into land use for solar developments in California, USA.[94] This could result in land use activities previously taking place on site to occur in new areas, resulting in impacts being created away from the site. Induced access through construction of roads into previously remote areas could lead to increased pollution or contamination, as well as natural resource collection, including of vulnerable species.
10	**Associated ecosystem service impacts**	Construction/ operation	Land take for solar developments and their associated facilities could lead to reduced access to, and the loss of important provisioning services such as areas important for agriculture or provision of natural resources. However, some developments are underway to combine these activities and preserve agricultural yields[95] and grazing areas.[96] Local communities may also feel a loss of cultural values, including a sense of place and belonging. Concerns relating to the visual impact of solar development are common. Ecosystem service impacts in relation to solar developments are not well understood[97] and require particular attention in early planning.
11	**Habitat alteration due to changes in microclimatic effects of solar panels**	Operation	Shadow effects caused by solar panels can alter the species composition and diversity of underlying habitats as a result of air and soil microclimate variation. A study of a UK solar plant revegetated with grassland showed that species diversity was lower under PV panels as a result of differences in soil and air temperature.[98] Differences in microclimate beneath panels have also preliminarily indicated that they can also help preserve vegetation such as crops during heatwaves and periods of drought.[99]
12	**Introduction of invasive alien species**	Construction	Movement of equipment, people or components may facilitate the introduction of invasive alien species (IAS) by various pathways, for example, by being transported in soil on machinery or attached to clothing. The creation of new habitats, for instance by land disturbance during construction or creating open spaces, may also facilitate the spread of IAS already present on the site.[100]
13	**Bird mortality due to being burned or singed by CSP infrastructure**	Operation	Birds that fly into the path of the concentrated light energy risk being burned or singed. Mortalities have been documented from several CSP farms in Israel, Spain and the USA.[101]

94 Hernandez et al. (2015).
95 Hoffacker et al. (2017).
96 Montag et al. (2016).
97 De Marco et al. (2014); Terrapon-Pfaff et al. (2019).
98 Armstrong et al. (2016).
99 Barron-Gafford et al. (2019).
100 Pathways for the spread of IAS are generally applicable to all types of construction projects. For some examples, see IPIECA & OGP (2010).
101 Ho (2016); Kagan et al. (2014). Other key references: Huso et al. (2016); McCrary et al. (1986).

4.2.2. Biodiversity most at risk

High biodiversity value landscapes

Utility-scale solar projects can individually and cumulatively cover large areas.[102] They sometimes also require new powerlines across unfragmented ecosystems and landscapes. Thus, land-cover change and soil disturbance can cause significant amounts of habitat loss and fragmentation, which is of particular concern in areas of high biodiversity value.[103] These may include protected areas, KBAs or areas of particular importance to threatened fauna and flora populations, including areas that qualify as Critical or Natural Habitat[104] (Section 3).

Arid ecosystems

Arid environments are often most suited for solar projects from a solar capture perspective. Compared to PV solar plants, CSP solar plants typically use a larger proportion of available water resources,[105] thus impacting aquatic or groundwater-dependent biodiversity and important ecosystem services. Impacts could include: i) habitat loss, fragmentation and drying of water bodies; and ii) loss of groundwater-dependent habitat where large amounts of water are withdrawn for operations.[106]

Birds

As well as habitat loss, birds are likely to be impacted by solar infrastructure due to collisions with project infrastructure (mirrors, PV panels, buildings, transmission lines), and possibly singeing events at CSP plants (Table 4-1). Nevertheless, initial evidence suggests that the collision risk posed by PV panels is likely low compared with that posed by transmission lines.[107] To date, there is little evidence to support the existence of the suggested 'lake-effect', where birds mistake PV panels for water bodies.[108]

In terms of collision with transmission lines, species with high wing loading (i.e. weight to wing area ratio) are at higher risk due to low manoeuvrability. Examples include bustards, cranes, storks, geese, swans, eagles and vultures. Flocking, migration and nocturnal activity are all associated with high collision levels in some species but are not consistently high-risk factors.[109]

Species at greatest risk from electrocution due to pylons of distribution lines are raptors and other large perching birds, which often use them as perches for hunting and as nesting sites. Moreover, their large wingspan makes it more likely for them to inadvertently create a short-circuit. Almost all electrocutions occur on low and medium voltage (<15 kV) lines: high-voltage power lines rarely have live and earthed components close enough for a bird to touch both at once. Risk factors associated with pylons include perching space on the live central pole or on the crossarm, and live jump wires on crossarms.[110]

Bats

As yet, there is no proven risk for bats from solar developments. Based on studies unrelated to the effects of solar panels on bats, it has been suggested that bats could be attracted to panels due to an increased number of insects or may mistake the panels for water bodies during echolocation.[111] Preliminary research in the UK observed lower bat activity over solar arrays than adjoining farmland during systematic surveys for a subset of the survey sites.[112] At any rate, impacts of solar plants on bats remain poorly investigated.

102 For example, see Hernandez et al. (2014).
103 For examples, see Kiesecker et al. (2020); Parker et al. (2018).
104 Hernandez, Easter, et al. (2014); Visser et al. (2019).
105 Macknick et al. (2012).
106 Grippo et al. (2015).
107 Harrison et al. (2016).
108 Kosciuch et al. (2020).
109 Bernardino et al. (2018).
110 Dixon et al. (2018).
111 See literature cited in Harrison et al. (2016).
112 Montag et al. (2016).

Aquatic insects

Preliminary research suggests that aquatic insects are highly attracted to the polarised light reflecting off PV panels.[113] The effects of this attraction in the field are little known but could have large effects in areas close to water bodies.[114] It is also hypothesised that insectivorous birds and bats can be attracted to the panels to feed on the insects,[115] although yet again, little is known of the knock-on effect on insect populations.

4.2.3. Population level and cumulative impacts

Where conditions favour solar energy, multiple developments can be concentrated within the same locality leading to cumulative impacts on habitats and species at the population level. For example, in the Mojave Desert ecoregion in Southern California, there has been rapid expansion of solar (and wind) infrastructure, with solar power resulting in the loss of around 130 km^2 of land in the Ivanpah Valley and Western Mojave regions[116] between 2010 and 2017.[117]

A large concentration of solar plants may also lead to increased levels of fragmentation and barrier effects to terrestrial species, particularly if the sites are fenced. Furthermore, collision mortality could theoretically have population-level effects on bird species. In the USA, for example, all utility scale solar facilities in operation or under construction are estimated to cause between 37,800 and 138,600 bird mortalities annually.[118] However, the extent and severity of these effects on species population viability requires further study.[119]

4.3 Project design phase mitigation

4.3.1. Overview

The project design phase typically begins once a site is identified and a decision made to invest in its development (Section 3). Risk and opportunity screening and/or review of existing strategic assessments as part of early project planning are fundamental to avoid placement of developments in sensitive sites (Section 3.4). Engineering design will consider solar plant size, PV or CSP technology type, layout and shading, electrical design, and location of site buildings to maximise energy production and minimise capital and operating costs. It will also need to account for constraints imposed by solar resource, topography, land use, local regulations, land use policy or zoning, environmental and social considerations, geotechnical considerations, geopolitical risks, accessibility, grid connection and financial incentives.

The identification of *avoidance* and *minimisation* measures to prevent and reduce adverse biodiversity and ecosystem service impacts are a primary consideration throughout the planning and design phase of a solar energy project. A robust biodiversity baseline early in the project design phase (Section 8.1) is essential for assessing the risk of an impact occurring, and identifying appropriate avoidance and minimisation measures. The most effective measures are often those that are planned early into the design, when changes in infrastructure siting and operational planning are still feasible. The process is iterative.

Avoidance and minimisation measures should be applied and reviewed repeatedly until impacts are either eliminated or reduced to a level where no net loss or net gain targets can feasibly be achieved through restoration and/or offsetting. The iteration is important because restoration and

113 Horváth et al. (2010).
114 Ibid.
115 Harrison et al. (2016).
116 Estimated figures from totals in Parker et al. (2018); around 52% of the total impacts recorded were due to solar developments.
117 Parker et al. (2018).
118 Walston et al. (2016).
119 Lovich & Ennen (2011).

offset measures can be costly, with a time lag in their realisation (Section 2.5). Optimising avoidance and minimisation measures early on reduces (or potentially removes) the need for expensive restoration and offsetting later. Hence, it is important to maintain close engagement throughout the design phase with project engineers, such that planned avoidance and minimisation measures are practical and implementable.

4.3.2. Avoidance and minimisation

After site selection, there are opportunities for mitigating biodiversity and ecosystem service impacts through design decisions. Avoiding and minimising impacts through project design for solar developments can involve two main measures implemented within a site:

- Changes to the layout of project infrastructure ('micro-siting' – see next section); and
- Re-routing, marking or burying powerlines.

Effective implementation of these measures requires a comprehensive biodiversity baseline, including identification of particularly sensitive areas on the project site, a good understanding of the behaviour of at-risk species and the ecosystem service-dependencies, and values that people place on nature at the site.

Micro-siting measures

Detailed and specific decisions regarding the location of individual components of project infrastructure are often termed '**micro-siting**'. Avoidance through micro-siting typically focuses on locating the entire solar plant or its components away from sensitive biodiversity areas and altering solar plant layouts to minimise barriers to movement.

Sensitive areas can be avoided on-site through relocation of solar panels, access roads, cabling or other infrastructure to avoid direct loss or degradation of sensitive habitat and decrease mortality risk of associated species. **Appropriate avoidance zones** can also be established around sensitive areas for biodiversity to minimise disturbance to at-risk species and edge effects. Some important areas for biodiversity are more sensitive at particular times of the year (e.g. during breeding times), and some may be sensitive due to a particular activity associated with solar plant development/operation. Mitigation of temporal impacts can be addressed through operational physical and abatement controls (Section 4.5.2).

Particularly sensitive areas to consider during project design include:

- Areas of threatened or vulnerable habitats or areas, where the life stage/behaviour of threatened or vulnerable species puts them at risk of impact;
- Important nesting, roosting and foraging areas for particular species;
- Landscape features that may concentrate species' movements, such as rivers, wetlands or forest edges;
- Areas along migratory corridors that support high concentrations of birds or large mammals (e.g. staging areas, stopover sites and 'bottleneck' areas); and
- Other natural features and important sites that people value or depend on for delivery of ecosystem services.

Options for altering solar plant layouts can include clustering solar arrays into blocks, employing adequate buffer zones between them, and fencing each block individually to avoid impacting sensitive areas along migratory corridors (Annex 2, case study 27).

Ecologists have recommended buffer zone distances for sensitive areas, species or species groups and these can be used for guidance. For example, in Alberta, Canada, buffer areas ranging from 45 m to 1,000 m are recommended for solar plant developments to minimise impact to important wildlife habitats.[120] Where there is no set buffer, expert input can help identify appropriate avoidance distances, using available information and applying it to the specific circumstances on site. Similarly, social experts can help identify appropriate buffer zones

120 Alberta Environment and Parks (2017).

around natural features of high cultural value or dependency by local communities.

Re-routing, marking or burying powerlines

Within solar plants, insulated cabling is usually buried or secured above ground, using hangers, cable trays, or cable ties, posing relatively little collision and electrocution risk to wildlife. However, high voltage transmission lines used to evacuate power from the solar plant can pose a collision risk to some bird species. Transmission lines should, as far as possible, be routed to avoid sensitive areas where there may be high traffic of birds at risk, for example, near wetlands or waste sites that may attract birds[121], and within bird migration corridors. This is a consideration in early planning, but further re-routing should be considered if more detailed information is available on the presence and movements of at-risk bird species (Section 8).

Marking transmission lines with bird diverters is now standard good practice, and on average has been shown to halve the numbers of collisions (Section 4.5.2).[122] However, this may not always be an effective solution for some species or under certain weather conditions, and thus may not be sufficient for risks to species of high conservation concern. Limited effectiveness may also be due to high device failure rates, and thus devices need to be monitored after installation. For large bats, electrocution risk can be reduced by orienting wires horizontally rather than vertically, as observed in frugivorous bats in Sri Lanka.[123]

Burying power lines poses technical challenges and costs, although it is an effective way of avoiding impacts where the lines pass through particularly sensitive areas to birds such as near wetlands and within bird migration corridors[124] and needs serious consideration in some cases. In some cases, a mix of marking and burying lines may provide the best outcome: for example, collisions with power lines caused a high mortality of great bustards in Austria and Hungary. When some lines were buried, and others marked with bird diverters, collisions were significantly reduced.[125]

However, it is recognised that burying of transmission lines could pose risks to biodiversity, particularly during its installation that requires consideration. In certain cases, major earthwork activities could result in the loss of habitat for plants, amphibians and/or reptiles of high conservation concern. It could also disrupt important linear features, such as rivers, and heighten the risk of invasive species ingress along the disturbed cable route. This measure is therefore a suitable alternative provided it is appropriately risk assessed. Where transmission lines run above ground, minimisation measures, such as bird diverters, will usually be needed (Section 4.5.2).

In some solar plants, power evacuation may be via medium-voltage lines. If poorly designed, these can pose a significant electrocution risk to many larger birds, especially birds of prey. It is however straightforward (and usually adds little, if any, cost) to construct safe distribution lines with insulation and spacing of conductors that eliminate electrocution risk for birds. Detailed guidance may be found in Annex 1.

121 Haas et al. (2004).
122 Bernardino et al. (2019).
123 Tella et al. (2020).
124 Bernardino et al. (2018).
125 Raab et al. (2012).

4.4 Mitigation in the construction phase

4.4.1. Overview

The project construction phase involves preparation of equipment and components, mobilisation of contractors, site preparation works (including land clearance, geophysical investigations and utilities), civil engineering works (including security perimeter fencing, buildings and access tracks/roads), construction of the electrical infrastructure (cabling from solar arrays, transformers, the on-site substation, and transmission lines to connect to the power grid), and installation of solar panel arrays and their associated structural components. Off-site grid connections are usually constructed in tandem with on-site works, and typically include upgrades to existing infrastructure or the construction of a new substation to connect to the existing electricity network.

Key *avoidance* and *minimisation* measures at this phase involve consideration of the construction works schedule and implementing physical, operational and abatement controls, including measures to protect existing vegetation and minimise soil disturbance through a robust construction management plan. Progressive ecological *restoration* of temporary facilities, such as lay-down areas or construction roads, and any Proactive Conservation Actions (PCAs), such as habitat creation or enhancement works (Section 7 and Box 17), will also need to be planned and implemented throughout construction.

In some cases, opportunities for new mitigation measures, or a more efficient implementation of the mitigation measures, are identified after the project design phase when construction has begun (or during the handover process from design to construction). Thus, minimisation by physical controls at this point involves modifying the physical design of project infrastructure during construction to reduce operation-related impacts on biodiversity and ecosystem services. Measures recommended to date mainly focus on modifications to solar arrays to reduce footprint impacts and any overhead transmission lines to reduce risk of bird collisions. Section 4.5.2 addresses those measures providing mitigation of impacts during the operational phase.

During the construction phase, unforeseen issues can arise that necessitate a change to the project design. This can result in further detrimental impacts to biodiversity and the associated ecosystem services, and could trigger the requirement to update the project ESIA and/or apply for amended consents. It is vital that any such changes are identified as early as possible to enable any additional ecological surveys and assessments required to be completed with minimal disruption to the construction programme.

Good practice mitigation measures for the construction phase are generally applicable to all types of developments, including solar developments, and can help identify appropriate practices to avoid and minimise impacts during project construction.

4.4.2. Avoidance through scheduling

Avoidance through scheduling involves **changing the timing of construction activities** to avoid disturbing species during sensitive periods of their lifecycle. This is the most effective means of construction phase mitigation, and is also an important consideration in avoiding/minimising aggregated and cumulative impacts (Section 3.2 and Box 6).

Construction schedules will need to consider seasonal aggregations (important/essential feeding, breeding and/or migratory periods) and diurnal/nocturnal activity and movement patterns of species of concern. For example, habitat clearance, grading and road construction activities typically cause the highest noise emission levels early in the construction phase of solar plants and may directly impact species that cannot easily move out of the way. Depending on their ecology and location of activities, small non-volant species, such as reptiles and amphibians, could be at either higher or lower risk during breeding or hibernation periods when they may be concentrated in particular habitats with limited adult (or juvenile) mobility.

Just as with project design, effective avoidance through scheduling requires a good understanding of the seasonal and diurnal activity patterns of sensitive species to be able to identify key periods to avoid. These may be linked to seasonality in the ecosystem, such as seasonal tree fruiting or forage availability, or the presence of temporary wetlands. Close collaboration between project planners, engineers, environmental specialists and contractors is required to ensure that mitigation through project scheduling is effective, in the same way as the implementation of a detailed management plan (Section 9).

4.4.3. Minimisation measures

Minimisation measures in the construction phase can be categorised into two types:

i) Operational controls

- Managing and regulating contractor activity and movement;
- Locating construction facilities away from sensitive areas, and limiting work vehicles, storage areas and machinery to designated construction and access areas on existing roads, where possible;
- Limiting the number and speed of vehicle movements to, from and within the solar plant area, especially during wet/winter periods, and prohibiting travel on unauthorised roads to protect existing vegetation and minimise soil inversion;
- Limiting natural vegetation clearance to the minimum necessary during construction works;
- Using new technologies to minimise drawdown of groundwater;
- Employing manual methods (e.g. hoeing or hand-pulling) to clear the ground of vegetation where possible to limit soil disturbance;
- Preventing the introduction, movement and spread of invasive species on and off the construction site, for example by washing down vehicles before they enter the site on designated areas;
- Installing sufficient drainage works under all access roads to reduce freshwater habitat fragmentation and avoid flooding land or damaging nearby waterbodies;
- Avoiding the creation of refuges for wildlife such as spoil heaps;
- Enforcing good behaviour by construction workers, including prohibition of hunting, trapping, fishing and general harassment of wild animals;
- Providing toolbox talks to all site personnel to ensure that they understand and are fully aware of the biodiversity mitigation measures for construction; and
- Having in place (and briefing site teams on) procedures for unexpected / unforeseen biodiversity issues arising during works, and for the reporting of and addressing any ecological incidents during works.

ii) Abatement controls

- Action to reduce emissions and pollutants (e.g. dust, light, noise and vibration, solid/liquid waste) that could negatively impact biodiversity and ecosystem services;
- Installing sensitive lighting plans for construction lighting (e.g. avoiding lighting sensitive wildlife areas);
- Implementing soil erosion and sedimentation control measures;
- Ensuring proper disposal of solid and liquid wastes and implementing a protocol for rapid management of any chemical leaks or spills; and
- Having in place a pollution prevention plan and any necessary equipment including spill kits.

Good practice mitigation measures should also be applied for waste management related to, for example, staff or contractor housing.

4.4.4. Restoration and rehabilitation

Some level of environmental damage is usually inevitable from the construction of solar developments associated with project-related impacts that could not be completed avoided or minimised. Thus, restoration work to repair this damage will be required. For areas of temporary project footprint, sensitive reinstatement to enable the habitat to return to its original condition and function should be undertaken in a phased approach concurrent with construction activities. Some 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 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.

Solar developments, particularly those located on degraded lands, such as agricultural areas, are encouraged to take further steps to employ PCAs (Section 7.2) to enhance the habitat on-site and create benefits for biodiversity and people.

4.5 Mitigation in the operational phase

4.5.1. Overview

Once commissioned, a solar plant is expected to operate continuously for a lifespan of approximately 25-30 years. Electricity generated by the solar plant is sold to customers, and the income used for loan repayment, operational and maintenance staff salaries, utility charges, landowners rent, local authority rates, project insurances, mitigation and offset measures, etc.

Apart from the high operational water demand of CSP technologies for cooling systems, solar plants generally have low maintenance and servicing requirements. Wet-cooling systems at CSP farms may, however, require significant amounts of cooling water (between 3,400 and 4,000 litres/MWh, which is three to four times more than conventional cooled coal plants).[126] In turn, this could alter the availability of surface and groundwater sources, particularly in arid regions. Scheduled technical maintenance is undertaken at regular intervals and includes activities, such as cleaning of panels through wet or dry methods (i.e. with or without water), checking electrical connections for issues, such as tightness or corrosion, and checking the structural integrity of the module mounting assembly, and other structures built on the solar plant. Unscheduled maintenance is also conducted when issues or failures arise.

Minimisation measures in the operational phase involve implementing physical and abatement controls (or *operational controls*).

4.5.2. Minimisation measures

Minimisation in the operational phase of a solar plant can be categorised as:

- Minimisation by **physical controls:**
    - Involving modification to the standard infrastructure to reduce impacts on biodiversity.
- Minimisation by **abatement controls**:
    - Involving action to reduce levels (e.g. dust, light, noise and vibration, solid/liquid waste) that could negatively impact biodiversity and ecosystem services.
- Minimisation by **operational controls**:
    - Involving managing and regulating activity and movement of operations and maintenance contractors, or land managers.

Physical controls

Minimisation by physical controls involves **modifying the physical design of project infrastructure** to reduce operation-related impacts on biodiversity. Measures recommended as yet mainly focus on modifications to solar technology and their associated foundations, implementing dry or hybrid cooling systems rather than wet cooling systems, and modifying security perimeter fencing and overhead transmission lines to decrease habitat fragmentation and reduce risk of collision and disturbance to at-risk species (Table 4-2).

126 Cain (2010).

Abatement controls

In general, limited process emissions is generated from operational solar plants other than increased polarised light levels and wastewater which may result in deleterious effects to wildlife (Table 4-1). Most measures recommended to reduce pollution levels at solar plants to date are listed in Table 4-2. Additionally, good practice mitigation measures, particularly wastewater management and water conservation measures, should be applied at CSP facilities as they produce significant amounts of process effluents in the form of wastewater, especially when employing wet cooling technologies.[127]

Some abatement actions undertaken at solar developments are not necessarily targeted towards minimising project impacts, rather they provide an opportunity to achieve additional benefits to biodiversity and associated ecosystem services (Section 7.2). Low-intensity 'conservation grazing' (using small- and medium-sized livestock such as sheep) on solar plants sited in agricultural land is one such measure increasingly adopted by countries in Europe and North America. It has been suggested as a cost-effective management measure to minimise pesticide use, encourage grassland diversification, and in some cases control invasive plant species, while enabling land to remain productive.[128] Such measures will need to be considered early in the project design phase as they may have implications for solar facility design. For example, increased ground clearance might need to be implemented to allow for grazing, while wires will need to be secured and rising cables armoured to avoid being disturbed by livestock.

Operational controls

Levels of human activity and movement associated with the operational phase of both CSP and solar PV plants are relatively low. Operational control measures recommended to date are mainly related to land management measures. This involves reinstating or altering vegetation and habitat conditions to provide suitable habitat for species not directly at risk of solar developments (Annex 2, case studies 7 and 28), including species of invertebrates, reptiles and small mammals. Such measures could include managing the timing of vegetation control activities at suitable intervals. For example, halting or reducing grazing activities within solar plants is recommended in agricultural areas in the UK during periods in spring and summer to promote flowering species that provide nectar to insects, while benefiting mammals and ground nesting birds (see also Section 7.2).[129] However, it should be noted that not all habitats can support grazing.

127 The Joint Institute for Strategic Energy Analysis (2015).

128 BRE (2014b).

129 Per IFC (2019) definitions.

Table 4-2 Description of key measures recommended for minimising biodiversity impacts at solar plants during operations

Measure	Receptor	Description	Examples evidencing effectiveness
Solar panels – *General*			
Minimise habitat loss/degradation by reducing foundation footprint	Natural habitat and associated species	Solar panels can be mounted on pile driven or screw foundations, such as post support spikes, rather than heavy foundations, such as trench-fill or mass concrete foundations, to reduce the negative effects on natural soil functioning, such as its filtering and buffering characteristics, while maintaining habitats for both below and above-ground biodiversity.	This measure has been recommended as good practice for mitigating impacts across solar developments.[130]
Modify security fencing to minimise barrier effects	Small- and medium-sized animals	Modifications to fencing can involve maintaining a gap between the base of the fence and the ground. This could occur across the full extent of, or at regular intervals, along the fence line.[131] This can also involve creating passageways by modifying the fence weave to facilitate animal movement.	This measure has been recommended as good practice for mitigating impacts across solar developments and other infrastructure development.[132]
Solar panels – PV specific			
Measures to reduce reflection effects	Aquatic insects	Non-polarising white tape can be used around and/or across panels to minimise reflection which can attract aquatic insects as it mimics reflective surfaces of waterbodies.	In a field experiment conducted in Hungary, aquatic insects, including mayflies, stoneflies, long-legged flies and tabanid flies, avoided solar panels with white tape on the border of and/or in a grid-like pattern across panels.[133]
Solar panels – CSP specific			
Measures to reduce reflection effects	Birds	Use of parabolic (curved) mirrors instead of flat heliostats to reduce the likelihood of skyward reflection to minimise potential bird collisions.	Measure suggested in literature but currently no studies to demonstrate its effectiveness.[134]
Measures to minimise singeing impacts	Birds	Use of technology, such as evacuated glass tubes, to reduce heat loss at trough receivers which lowers receiver temperatures, thus minimising singeing impacts.	Measure suggested in literature but currently no studies to demonstrate its effectiveness.[135]

130 Refer to examples such as Building Research Establishment (BRE) (2013); Peschel (2010); Science for Environment Policy (2015).

131 Size specifications of these gaps vary and include, 10-15 cm in height as recommended by BRE (2014a) and Peschel (2010) or gap dimensions of 20 x 20 cm or 30 x 30 cm as recommended in France.

132 For example, see: Building Research Establishment (BRE) (2013); Peschel (2010); Science for Environment Policy (2015).

133 Horváth et al. (2010).

134 BirdLife International (2015).

135 Carbon Trust (2008).

Measures to reduce water use	General	Employ dry instead of wet cooling and cleaning technologies, such as air cooling (dry cooling and cleaning), to reduce water use and address impacts to aquatic biodiversity and ecosystem services. Storing steam in pressurised tanks can be used to generate energy at night when it is cool, reducing the water required by cooling systems.[136] Similarly, energy generated during the day can be stored using molten salt, further reducing water requirements of CSP plants.[137] Water reclaimed from municipal wastewater treatment plants (i.e. treated effluent) can represent a relatively reliable source of cooling water for CSP plants located close to urban areas.[138] Land management through revegetation under panels and around solar development with naturally occurring species may reduce dust, and thereby reduce the amount of water required for cleaning solar collection and reflective surfaces in both PV and CSP farms.[139]	Studies on groundwater drawdown under different pumping scenarios in six states in the USA found that application of dry cooling technologies could reduce water drawdown from the aquifer from as deep as 110 m to as low as 15 m over 20 years.[140] All other measures suggested in literature but currently no studies to demonstrate its effectiveness.
Measures to prevent drowning or poisoning of wildlife	All wildlife	Fencing and wire meshing can be used to keep wildlife away from evaporation and wastewater treatment ponds.	This measure is considered good practice, in light of evidence showing mortalities and long-term deleterious effects associated with use of ponds, as shown in Section 4.2.1.
Overhead power lines			
Measures to reduce collision risk	Birds	Attaching bird flight diverters (typically flappers, balls or spirals) to transmission grounding wires to increase their visibility. Table 5-3 presents the different design options and examples of effective application.	Evidence for the effectiveness of this measure is fairly robust. An analysis of 35 studies on the effectiveness of wire-marking in reducing bird collisions with power lines revealed that average collision mortalities was reduced by 50%, with the type of device having no influence on this effect.[141] New technologies are emerging, such as illuminating with UV lighting,[142] although their widespread effectiveness is unproven.
Wildlife-safe design or retrofitting power-line wires and poles	Birds	Designing low- or medium-voltage powerlines, or adding insulation to existing poles and wires, to reduce the risk of electrocution of birds or other wildlife from contact. Evidence proving the effectiveness of this measure is robust.	In Mongolia, retrofitting of insulation on low-voltage power pylons resulted in an estimated 85% reduction in mortalities.[143]

136 Bucknall (2013).
137 Bielecki et al. (2019); Bucknall (2013).
138 Carter & Campbell (2009).
139 Beatty et al. (2017); Macknick et al. (2013).
140 Adapted from Grippo et al. (2015).
141 Bernardino et al. (2019).
142 Dwyer et al. (2019).
143 Dixon et al. (2018).

Altering transmission line configurations	Birds and bats	Measures to change the design of transmission lines to reduce bird collisions aim to reduce the vertical spread of lines, increase the visibility of lines, and/or decrease the span length. Specific measures could include: (i) reducing the number of vertical wire levels by adjusting the conductor heights to reduce the number of potential collision points; (ii) stringing wires as low as possible; (iii) keeping wire span lengths as short as possible to minimise line height as birds usually respond to seeing lines by increasing height; and (iii) using wires with a thicker diameter or bundling wires to increase visibility.	While these measures are generally agreed upon and recommended, further scientific evidence is needed to clearly demonstrate their effectiveness.[144] In Sri Lanka, electrocution risk to fruit bats was found to be almost zero for powerlines with wires oriented horizontally. Vertically oriented powerlines accounted for 94% of electrocuted individuals.[145]

4.6 End-of-life

4.6.1. Overview

Broadly, at the end of the operational life of a solar plant, the options are to: (i) extend the operational life of the existing assets; (ii) repower the site (Section 4.6.3); or (iii) fully decommission the site. Both repowering and decommissioning provide opportunities to undertake further mitigation and are the focus of this section.

4.6.2. Repowering

Other than the options of decommissioning and end-of-life extension, **repowering** is the other option that can be undertaken for solar plants facing the end of their operational lifespan. Repowering is undertaken by conducting a comprehensive upgrade of solar infrastructure, such as panels and inverters, or alternatively through retrofitting by replacing certain specific components with newer models.

Repowering brings the solar project back to the **start of its life cycle process** and provides an opportunity to address existing negative biodiversity and associated ecosystem service impacts, including impacts to particular species of concern. In some cases, repowering solar plants on previously degraded land can further serve to maintain the benefits to biodiversity and associated ecosystem services that has resulted from positive impacts associated with proper application of the mitigation hierarchy (Section 2.5) and adopting suitable PCAs (Section 7.2).

In general, mitigation measures detailed in Sections 4.3, 4.4 and 4.5 should be re-considered at this phase, with certain specific considerations requiring careful attention.

Avoidance through project design

Repowering provides the opportunity to site solar infrastructure more thoroughly to minimise barriers to wildlife movement (Section 4.3.2 for mitigation measures related avoidance through changes to the siting of project infrastructure).

Effective avoidance through repowering requires a comprehensive monitoring dataset to understand the interactions of wildlife with the existing solar plant layout (Section 8.2 for more information on approaches to good practice monitoring). For example, large solar plants can relocate solar arrays into blocks, employ adequate buffer zones between them, and fence each block individually to avoid impacting sensitive areas along migratory corridors for ungulates such as deer and antelope.

144 Bernardino et al. (2018).
145 Tella et al. (2020).

4.6.3. Decommissioning

The decision to decommission could be driven, in part, by the solar plant site lease, depending on land ownership considerations. Decommissioning is the removal or making safe of solar plant infrastructure at the end of its useful life.

The decommissioning phase involve the dismantling and removal of security perimeter fencing, buildings and access tracks required for operation, electrical infrastructure (transformers, the on-site substation and transmission lines connected to the power grid), and solar panel arrays and their associated structural components.

Avoidance and minimisation measures

Decommissioning is essentially the reverse of the construction phase, employing many of the same procedures and equipment used during construction. Hence, construction phase avoidance through scheduling and minimisation by abatement and operational controls will also generally apply here. Considerations include:

- **Reviewing** the monitoring dataset accumulated over the project lifecycle and undertaking field surveys, if needed, to confirm the sensitive species for consideration during decommissioning;
- **Avoiding** decommissioning work during **sensitive periods** of species' lifecycles. Scheduling will need to account for seasonal aggregations (e.g. critical breeding and/or migratory periods) and diurnal/nocturnal movement patterns, and requires a good understanding of the seasonal and diurnal activity patterns of sensitive species to identify key periods to avoid. Such avoidance periods may be linked to seasonality in the ecosystem, such as seasonal tree fruiting or forage availability, or the presence of temporary wetlands;
- **Minimising** habitat disturbance during infrastructure removal;
- **Minimising** noise impacts on fauna associated with infrastructure removal procedures;
- **Accounting** for and addressing potential social and ecosystem **service** impacts arising from biodiversity mitigation;
- **Managing** waste disposal and implementing a protocol for rapid management of any chemical leaks or spills;
- **Ensuring** good practice for reuse, recycling or disposal of decommissioned components; and
- **Enforcing** good behaviour by decommissioning workers, including prohibition of hunting, trapping, fishing and general harassment of wild animals.

Restoration

After decommissioning, the site should be reinstated to its original state as far as feasible, or in accordance with national requirements and/or land lease agreements made with landowners. End-of-life solar plant infrastructure components including solar panels and aluminium and copper cables will need to be recycled or otherwise disposed of responsibly (Section 10). Restoration measures following good environmental practices should be the focus during this phase (Section 4.4.4).

Decommissioning solar plants is not dissimilar to other onshore power generation facilities, such as mining and oil and gas, as they share similar civil and electrical infrastructural components. Hence, good practice mitigation measures will be applicable across all types of onshore developments, including solar developments.

Table 4-3 summarises the mitigation approaches addressed in this chapter for solar power developments.

4.7 Summary of mitigation approaches for solar

Table 4-3 summarises the mitigation approaches addressed in this chapter for solar.

Table 4-3 Summary of mitigation approaches for solar power projects

Project phase	Mitigation hierarchy	Approach
Project design phase	Avoidance and minimisation	Micro-siting: changing the layout of project infrastructure to avoid sensitive areas Re-routing, marking or burying powerlines to avoid collision risks and barrier effects
Construction phase	Avoidance	Scheduling: changing the timing of construction activities to avoid disturbing biodiversity during sensitive periods
	Minimisation	Abatement controls to reduce emissions and pollutants (noise, erosion, waste) created during construction Operational controls to manage and regulate contractor activity, such as exclusion of fencing around sensitive areas, designated machinery and lay-down areas, minimising vegetation loss and disturbance to soil
	Restoration and rehabilitation	Repair of degradation or damage to biodiversity features and ecosystem services from project-related impacts that cannot be completely avoided and/or minimised by revegetating of temporary-use and lay down areas as soon as reasonably practicable after construction activities are complete
Operational phase	Minimisation	Physical controls involving modification to infrastructure, or its operation, to reduce impacts (e.g. modifications to solar technology and their associated foundations, implementing dry or hybrid cooling systems rather than wet cooling systems, and modifying security perimeter fencing and overhead transmission lines) Abatement controls including wastewater management and water conservation measures at CSP facilities) Operational controls to manage and regulate contractor activity such as managing the timing of vegetation control activities at suitable intervals)
End-of-life	Avoidance	Scheduling: changing the timing of decommissioning activities to avoid disturbing biodiversity during sensitive periods (e.g. during breeding seasons)
	Minimisation	Abatement controls to reduce emissions and pollutants (noise, erosion, waste) during decommissioning and repowering Operational controls to manage and regulate contractor activity through, for example, exclusion fencing around sensitive areas, designated machinery and lay-down areas)
	Restoration and rehabilitation	Repair of degradation or damage to biodiversity features and ecosystem services from project-related impacts that cannot be completely avoided and/or minimised by revegetating temporary-use and lay down areas as soon as reasonably practicable after construction activities are complete Reinstatement of original vegetation, as far as feasible, following decommissioning

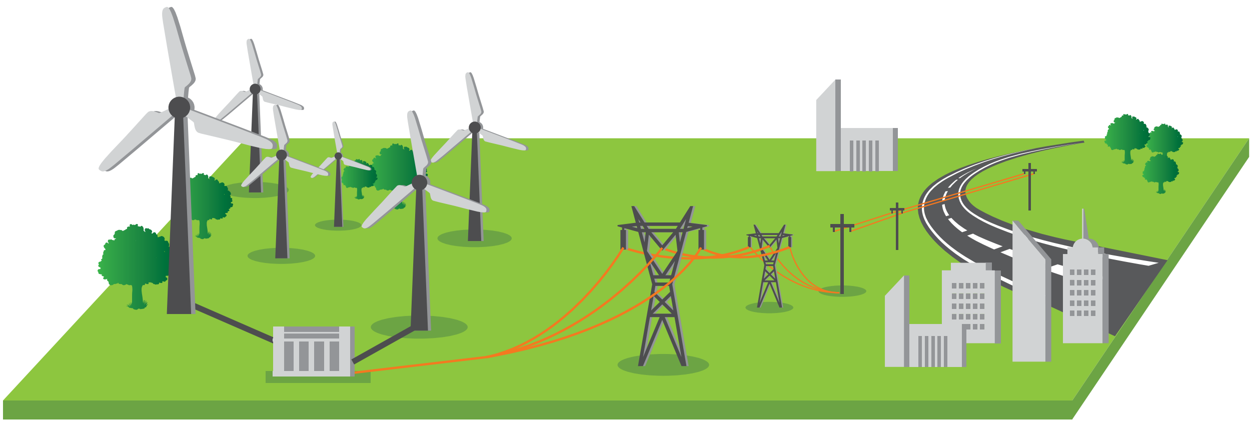
5. Onshore wind energy – Potential impacts and mitigation approaches

5.1 Overview of an onshore wind development

This chapter presents an overview of the primary biodiversity and ecosystem service impacts of onshore wind energy, followed by discussion of the key mitigation approaches that can be employed at each project stage (design, construction, operation and end-of-life).

An onshore wind project typically comprises: (i) a series of turbines; (ii) a collector sub-station; (iii) a network of access roads with cabling that run between the substation and each turbine; and (iv) a high-voltage power line from the substation that connects to the local power grid (Figure 5.1). New onshore wind turbines have up to 5 MW generation capacity, with maximum hub heights of about 160 m and rotor diameter of about 160 m. Nameplate capacity and size are continually increasing. Turbines are typically spaced more than 500 m apart to minimise wake effects (the wake of one turbine reducing the generation potential of the next), and arrays of turbines are typically placed perpendicular to the prevailing winds.

Figure 5.1 Overview of key project components of an onshore wind development



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5.2 Impacts of onshore wind energy on biodiversity and ecosystem services

5.2.1. Summary of key impacts

Studies on biodiversity impacts of onshore wind have focused mainly on birds, bats and natural habitats, with limited understanding of impacts to other taxa, including non-flying mammals.

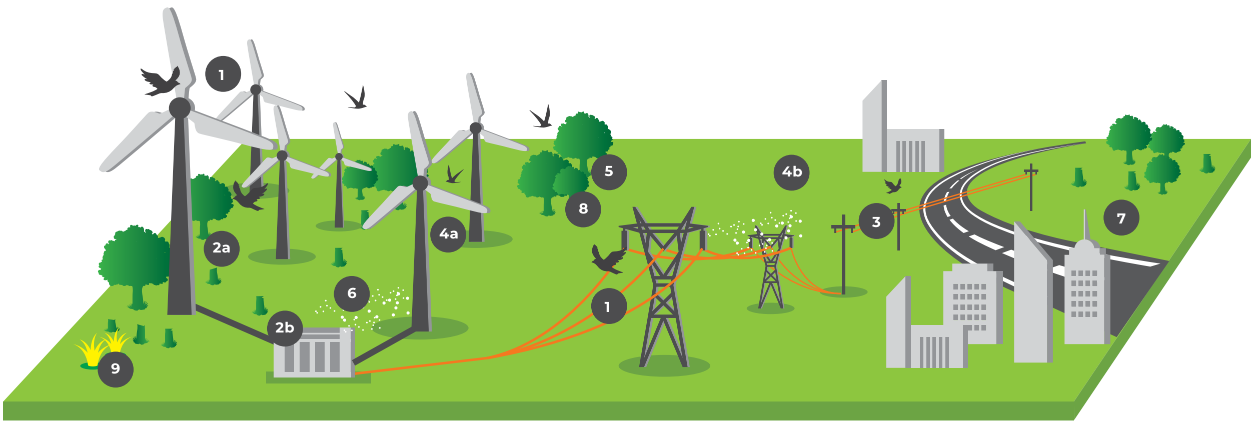
Wind energy developments can affect birds and bats through direct mortality and through loss and degradation of their habitat, and this effect is well-documented for both species groups. The ability to predict fatality levels is more advanced for birds than bats, while there is comparatively little knowledge on population-level impacts for either birds or bats. This is particularly the case for the tropics and sub-tropics where diversity is high, and wind power is expanding rapidly.[146]

Terrestrial species are generally affected by changes in the structure and function of their habitat, and these changes may be both from the wind farm or associated infrastructure. Few examples exist linking the operation of wind farms to direct impacts on terrestrial species, and impacts are likely to be location and species specific.[147] However, barrier effect, noise, vibration, shadow flicker and electromagnetic field generation, and increased fire risk (due to increased anthropogenic activity), may directly impact terrestrial species.[148]

Ecosystem service impacts may include a loss of, or restrict access to, locally important provisioning services, such as livestock grazing or agricultural land, or loss of cultural values, including visual impacts on the landscape. The level of these impacts will vary globally with the local intensity of, for example, land transformation, small-scale agriculture or reliance on non-timber forest products.

Figure 5.2 illustrates an overall view of the impacts of onshore wind developments on biodiversity, and Table 5-1 presents a more detailed list of specific impacts on birds, bats and natural habitats.

Figure 5.2 Potential impacts of onshore wind developments on biodiversity and associated ecosystem services. Please see Table 5-1 for details on each impact type



1. Bird and bat collisions with turbines blades and / or transmission lines, as well as possibly barotrauma
2. Habitat loss through clearance or displacement of land for construction of, (a) wind turbines and (b) associated facilities
3. Bird and bat mortality through electrocution on distribution lines
4. Barrier effects to to animal movement from, (a) closely-spaced turbines, (b) roads, and transmission lines.
5. Trophic cascade effects affect predator-prey dynamics and ecosystem function
6. Pollution (e.g. dust, light, noise and vibration, solid/liquid waste)
7. Indirect impacts from displaced land-uses, induced access or increased economic activity
8. Associated ecosystem service impacts
9. Introduction of invasive alien species

146 For example, Arnett & May (2016); Barclay et al. (2017); de Lucas & Perrow (2017).

147 See also Ferrão da Costa et al. (2018)a; Łopucki & Mróz (2016); Rabin et al. (2006).

148 Lovich & Ennen (2013).

Table 5-1 Summary of the key biodiversity and associated ecosystem service impacts of onshore wind developments. The significance of particular potential impacts will be context-specific

No.	Impact type	Project stage	Description and examples
1	Bird and bat collisions with turbines blades and/or transmission lines	Operation	Birds flying in the turbine rotor swept zone are potentially at risk of collision and serious injury or death. In the United States, for example, the median annual fatality estimate at wind energy facilities is 1.8 birds per MW,[149] while in South Africa and Canada the estimated mean annual fatality is 4.6 and 8.2 birds per turbine per year, respectively.[150] As these are median values, poorly sited wind energy facilities can have considerably higher fatalities. The diversity of birds killed by turbines can also be high. A four-year study of 20 wind farms in South Africa found mortality of 130 species from 46 families, totalling 30% of bird species recorded at and around the wind farms. Species accumulation models suggest that this may be as high as 42%.[151] Collisions with the (thin and hard to see) earth wire of transmission lines may lead to significant fatalities for some species such as bustards.[152] For bats, most studies to date on turbine collision risk are in the north temperate zone. In North America, carcasses were dominated by migratory, foliage- and tree-roosting bat species, with fatalities increasing at: (i) low wind speeds; and (ii) before and after passage of storm fronts.[153] The majority of species killed by turbines are adapted for foraging insects in open spaces, high above the ground and far from vegetation.[154] Mortality was usually the highest during low wind speeds and increased with turbine tower height and rotor diameter.[155] As for birds, collision risks are both for resident and migratory species. While barotrauma (injury caused by sudden pressure changes) has been hypothesised as a major source of bat mortality at wind turbines,[156] it does not appear to be an important source of bat mortality.[157]

149 AWWI (2019).
150 Perold et al. (2020); Ralston Paton et al. (2018); Zimmerling et al. (2013).
151 Perold et al. (2020).
152 Mahood et al. (2017).
153 Arnett et al. (2008).
154 Denzinger & Schnitzler (2013); Thaxter et al. (2017).
155 Rydell et al. (2010).
156 Baerwald et al. (2008).
157 AWWI (2019).

2	Habitat loss through clearance or displacement	Construction/ operation	The physical footprint of wind power turbines and access roads is usually relatively small. However, some species avoid wind farms, resulting in displacement and effective loss of habitat. Avoidance of turbines varies between species and locations, with avoidance distances also scaling with the size of the turbine.[158] Installation of wind turbines in Portugal resulted in black kites (*Milvus migrans*) avoiding 3%–14% of their previously used habitat in the area.[159] The response of bats to turbines differs across species and locations. Bats may actively avoid turbines or may be attracted to feed around them.[160] For example, forest clearance could affect bats through loss of roosting and foraging habitat. At the same time, the construction of roads and turbine arrays could create new foraging habitat for species that prefer foraging along forest edges and gaps.[161] The response to the presence of wind farms appears to be species-specific, with some species showing varying levels of avoidance.[162] Such species include both large mammals, such as the European roe deer (*Capreolus capreolus*), and smaller mammals such as the European hare (*Lepus europaeus*) and red fox (*Vulpes vulpes*).[163] In Portugal, wolves were found to avoid denning near wind farms by distances up to 6.4 km. Such responses can lead to significant cumulative impacts if wind farms are located in areas of limited breeding habitat; there can also be further impacts to the trophic cascade.[164] For example, a study on California ground squirrels (*Spermophilus beecheyi*) observed increased anti-predator behaviour near turbines.[165] Such behavioural changes may decrease foraging efficiency and lead to a shift in population dynamics (see row no. 5 'Trophic cascades').
3	Bird and bat mortality through electrocution on distribution lines	Operation	Electrocution rates at the pylons (or poles) of low- or medium-voltage lines can be high and disproportionately affect some species that use pylons of low-voltage lines as perches when hunting or for nesting. An annual mortality rate of around 0.7 birds per pole was estimated as a result of electrocution on a distribution line in southern Morocco.[166] Electrocutions may be partially responsible for the decline of some long-lived species. For example, electrocution of Egyptian vulture (*Neophron percnopterus*) over a 31-km stretch of powerline in Sudan is thought to have resulted in sufficient deaths to partially explain their population decline.[167] Electrocutions are rarely significant at the pylons of high-voltage transmission lines. There is limited evidence of risks to bats, although electrocution of large bat species, particularly fruit bats, has been identified as an issue associated with distribution lines.[168]

158 See review in Hötker (2017).
159 Marques et al. (2019).
160 Cryan et al. (2014); Foo et al. (2017). Other key references : Arnett et al. (2016); Millon et al. (2015; 2018); Minderman et al. (2012).
161 Barclay et al. (2017).
162 Pearce-Higgins et al. (2012).
163 Łopucki et al. (2017).
164 Ferrão da Costa et al. (2018a).
165 Rabin et al. (2006).
166 Godino et al. (2016).
167 Angelov et al. (2013).
168 Kundu et al. (2019); O'Shea et al. (2016); Tella et al. (2020).

4	Barrier effects	Construction/ operation	Multiple wind farms in the same landscape may create barriers for bird species although such impacts have not been extensively studied. As some species do show high collision avoidance rates, it is likely that their flight paths will change, especially if there are large numbers of closely-spaced turbines in a landscape. Migratory birds are particularly affected by wind turbines as they often travel in large flocks along set routes. Any obstacles blocking their flight paths will not only cause fatalities but may force them to burn crucial energy reserves diverting their route or abandon much-needed rest stops altogether. For example, migrating raptors appear to adjust their flight trajectories to avoid new wind farms.[169] Such barrier effects may become increasingly apparent as more wind farms are developed and monitoring (including of tagged birds) improves. Barrier effects may also affect terrestrial species if wind farms are fenced, particularly large migratory mammals.
5	Trophic cascades	Operation	Changes in species abundance with the presence of wind farms can affect predator-prey dynamics and ecosystem function: the nature and prevalence of this impact is still poorly understood. One example from India showed increased lizard abundance and behavioural changes within a wind farm footprint due to the avoidance of the area by their main raptor predators.[170] The effect of trophic cascades may become better understood with long-term monitoring.
6	Pollution (dust, light, noise and vibration, solid/ liquid waste)	Construction/ operation	Construction and operations can result in water, noise, dust and light pollution impacts. Although examples of impacts related to wind developments are limited,[171] they have been widely demonstrated for other types of infrastructure development.
7	Indirect impacts	Construction/ operation	Wind power projects generally have a small physical footprint and a small complement of staff once construction is complete. Despite this, localised indirect impacts (e.g. from displaced land-uses, induced access or increased economic activity) may still be significant. In some cases, land take for wind farm developments and their associated facilities may displace other land uses such as agriculture elsewhere. Induced access through construction of roads into previously remote areas may lead to increased pollution or contamination, natural resource collection or exploitation of vulnerable species. Examples specific to wind developments are not currently available.[172]
8	Associated ecosystem service impacts	Construction/ operation	Land needed for the development of wind farms and their associated facilities could lead to reduced access to, and the loss of, important provisioning services such as areas important for agriculture or provision of natural resources. Local communities may also feel a loss of cultural values (e.g. where sacred sites are impacted), including a sense of place and belonging. Wind farms may also impact the aesthetic value of an area, in turn negatively impacting the tourism potential or land value. These associated ecosystem service impacts could have adverse effects on the well-being of local people.
9	Introduction of invasive alien species	Construction	Movement of equipment, people or components may facilitate the introduction of invasive alien species (IAS), for example through its transport in soil on machinery or attached to clothing, etc. The creation of new habitats, for instance by land disturbance during construction or by creating open spaces, may also facilitate the spread of IAS already present on the site. At the Serra da Lousã wind farm in Portugal, two new IAS were found during operational monitoring, while two IAS already present were shown to have spread along access roads and turbine pads.[173]

** Numbers used refer to the illustration in Figure 5.2.*

169 Cabrera-Cruz & Villegas-Patraca (2016).

170 Thaker et al. (2018).

171 See Perrow (2017) for discussion of impact pathways for various species groups.

172 Ledec & Posas (2003).

173 Silva & Passos (2017).

5.2.2. Biodiversity most at risk

Birds

Small passerines. Some species are disproportionately represented by fatalities at wind farm impacts, due to their abundance, biology or behaviour. The majority of bird fatalities at wind farms are small passerines.[174] However, impacts on these species are thought to be rarely significant at population level due to (in most cases) relatively large population sizes and short generation times; the exception to this could be for rare, declining or restricted range species.

Large, soaring birds. Species most at risk from collision with wind turbines are generally large, soaring species that rely on updrafts for the majority of their long-distance flights. These species may not be manoeuvrable enough to change flight paths quickly and may also have a restricted forward field of view meaning they don't detect turbine blades, all factors that make them more susceptible to collision.[175] Examples of species more at risk include vultures, many soaring raptors and storks. These species typically have long generation times and relatively small populations, increasing the potential for population-level effects from any fatalities.

Migratory species. In general, migratory species are more prone to collision than more sedentary species.[176] However, fatalities at a wind farm are often higher for resident species as they undertake many more flights that are at risk of collision than migratory species.[177]

Species with high wing loading (body mass to wing area ratio). Bustards, cranes, storks, geese and swans, eagles and vultures are at higher risk of collision with transmission lines due to low manoeuvrability. Flocking, migration and nocturnal activity are all associated with high collision levels in some species but are not consistently high-risk factors.[178]

Large perching birds. The species at greatest threat from electrocution at the pylons of wind farm-associated powerlines are raptors and other large perching birds. These birds often use electricity pylons as perches for hunting and as nesting sites, and their large wingspan increases the chance of them inadvertently creating a short-circuit. Almost all electrocutions occur on low and medium voltage (<15 kV) lines; high-voltage power lines rarely have live and earthed components close enough for a bird to touch both at once. Risk factors associated with pylons include the dimensions of the perching space on the live central pole or cross-arm, and the presence of live jump wires on cross-arms.[179]

Bats

The understanding of species' risk factors is advancing for insectivorous bats. By contrast, there is very little information available on the impacts of wind energy and risk factors for fruit and nectar feeding species ('plant-visiting bats'),[180] as most studies to date are in the northern temperate zone, where there are few species of plant-visiting bats. The known risk factors for insectivorous bat species cannot be applied to fruit and nectar feeding bats, as these species have a wide range of characteristics (e.g. many different wing shapes) that differ to insectivorous species, have different food sources and do not tend to echolocate; meaning their patterns of movement and responses to infrastructure are likely to be different.

The UK's national guidelines list a suite of physical and behavioural characteristics that increase bat collision risk based on bat morphology and behaviour and fatality data from across the UK and Europe.[181] These can likely be generally applied to insectivorous bat species globally. Collision risk is greater for species that display the following characteristics:

- Forage in open habitat;

174 AWWI (2019); Dürr (2019).
175 Marques et al. (2014); Martin & Shaw (2010).
176 Thaxter et al. (2017).
177 Marques et al. (2014).
178 Bernardino et al. (2018).
179 Dixon et al. (2018).
180 Arnett & May (2016); Barclay et al. (2017).
181 Scottish Natural Heritage et al. (2019).

- Long range, low frequency and high intensity echolocation;
- Long and narrow wing shape with a high aspect ratio and high wing loading;
- Fast flight speed;
- Commuting flight behaviour across open landscape;
- Aerial hawking foraging technique and open-air foraging; and,
- Long-distance migrant in some parts of range.

These features are consistent with the profile of high-risk species identified in other studies.

Open air foragers, adapted to flight and echolocation in open habitats, are suggested to be of highest risk as they regularly fly within the rotor swept zone. This appears to be the case regardless of migratory pattern and roost preferences, and is shown to be consistent across Europe, North America and Mexico.[182]

Long-distance migratory species have been suggested to have significantly greater collision rates then sedentary species.[183] However, this observation has not been consistent across the world, and could be biased towards the well-studied regions of North America and to some extent northern Europe.[184]

Natural habitats and other high biodiversity value areas

Utility-scale onshore wind projects, plus associated infrastructure, can individually and cumulatively cover large areas, causing significant amounts of habitat loss and fragmentation. This is of particular concern in areas of high biodiversity value,[185] which may include protected areas, KBAs or habitat of importance for threatened fauna and flora populations.

5.2.3. Population level and cumulative impacts

Birds

Compared to the impacts of individual wind farms, cumulative impacts of onshore wind power on birds have had only limited consideration. At a population level, migratory bird species and those that forage over large ranges may experience significant cumulative mortality as a greater proportion of the population may encounter multiple turbines during their movements, in addition to other human-caused risks.

The fatality levels recorded at individual wind farms in the United States are considered unlikely to lead to population-level impacts for passerines or wetland bird species, but potential population-level effects may occur for some diurnal raptors.[186]

Examples where the cumulative impacts of multiple wind projects have been considered include Tafila, Jordan,[187] for four species of threatened Australian birds,[188] and at the national level for Kenya.[189] In Tafila, any cumulative effect was considered unacceptable for multiple species so all wind farms have committed to a zero fatality target for those species through mitigation, while in Australia, no population-level impacts were predicted for any species prior to mitigation due to low absolute numbers of any species at the wind farm sites. In Kenya,[186] the Potential Biological Removal[190] value was used to examine which species may be most at risk at the population level from potential cumulative impacts of wind farms at a national scale.

182 Arnett & May (2016).
183 Thaxter et al. (2017).
184 Arnett & May (2016).
185 Kiesecker et al. (2020); Parker et al. (2018); Rehbein et al. (2020).
186 AWWI (2019); Bellebaum et al. (2013).
187 IFC (2017).
188 Smales (2006).
189 TBC et al. (2019).
190 Potential Biological Removal is a measure of the number of individuals that can be removed from a population annually by human-induced mortality without causing noticeable population-level effects.

Bats

Only a handful of studies in North America and Europe have attempted to assess cumulative bat mortalities from wind projects. Bat fatalities from wind farms across the United States are estimated to be between 650,000 and 1,3 million between 1999–2010, while more than two million bats may have been killed by wind turbines over the past decade in Germany.[191]

Unfortunately, little to no population data exist for most bat species globally, which hinders understanding of the impacts of wind energy projects on long-term population viability. Studies have tried to overcome this data limitation by developing pragmatic approaches to assess the cumulative impact of wind projects. One such study used expert opinion and population projection models to show that fatalities at wind farms of the hoary bats (*Lasiurus cinereus*), a widespread migratory species most commonly killed by wind turbines in North America, may significantly reduce population size and increase the risk of extinction.[192]

Conservation status is an important factor influencing population-level and cumulative risk. Impacts associated with wind power development may be more significant for threatened species because they may have a small population size[193] a restricted range,[194] ongoing population decline (or habitat loss),[195] or face current or future threats,[196] which are driving species decline.

5.3 Project design phase mitigation

5.3.1. Overview

The project design phase typically begins once a site is identified, and a decision taken to invest in its development (Section 3). Risk and opportunity screening and/or review of existing strategic assessments as part of early project planning are fundamental to avoid placement of developments in sensitive sites. Engineering design will consider wind farm size, turbine type, hub height, layout and electrical design to maximise energy production and minimise capital and operating costs. It will also need to account for constraints imposed by wind resource, topography, land use, local regulations and land use policy or zoning, environmental and social considerations, geotechnical considerations, geopolitical risks, accessibility, grid connection and financial incentives.

The identification of *avoidance* and *minimisation* measures to prevent and reduce adverse biodiversity and ecosystem service impacts are a primary consideration throughout the planning and design phase of an onshore wind project. A robust biodiversity baseline early in the project design phase is essential for assessing the risk of an impact occurring (Section 8.1) and identifying appropriate avoidance and minimisation measures. The most effective measures are often those that are planned into design early, when changes in infrastructure siting and operational planning are still feasible. The process is iterative.

Avoidance and minimisation measures should be applied and reviewed repeatedly until impacts are either eliminated or reduced to a level where any remaining impacts can be managed to acceptable levels through restoration and/or offsetting. The iteration is important because restoration and offset measures are often uncertain, can be costly, and carry a time lag in their realisation (Section 2). Optimising avoidance and minimisation measures

191 Arnett & May (2016).
192 Frick et al. (2017).
193 O'Grady et al. (2004); Shaffer (1981).
194 Manne & Pimm (2001).
195 O'Grady et al. (2004).
196 IUCN (2019).

early on thus reduces (or potentially removes) the need for expensive restoration and offsetting later. Hence, it is important to maintain close engagement throughout the design phase with project engineers, such that planned avoidance and minimisation measures are practical and implementable.

5.3.2. Avoidance and minimisation

After site selection, there are opportunities for mitigating biodiversity and ecosystem service impacts through design decisions. Avoiding and minimising impacts through project design for onshore wind developments often involves two main measures implemented within a site:

- Changes to the layout of project infrastructure (termed 'micro-siting'); and
- Re-routing, marking or burying powerlines.

Effective implementation of these measures requires a comprehensive biodiversity baseline, including identification of particularly sensitive areas on the project site and a good understanding of the behaviour of at-risk species and the ecosystem service-dependencies and values that people place on nature at the site.

Micro-siting measures

Detailed and specific decisions regarding the location of individual pieces of project infrastructure is often termed as '**micro-siting**'. Avoidance through micro-siting typically focuses on placing development, or components of development, away from sensitive biodiversity areas and altering wind farm layouts to minimise barriers to movement (Annex 2, case study 6).

Sensitive areas can be avoided on site through relocation of turbines, access roads, cabling or other infrastructure, to avoid direct loss or degradation of sensitive habitat, reduce habitat fragmentation and barrier effects, and decrease mortality risk of associated species. Some important areas for biodiversity are more sensitive at particular times of the year such as for breeding, and some may be sensitive due to a particular activity associated with onshore wind farm development/operation. Mitigation of temporal impacts can be addressed through operational physical and abatement controls, and is addressed in Sections 8.2 and 8.3.

Particularly sensitive areas to consider during project design include:

- Areas of threatened or vulnerable habitats or areas where the life stage/behaviour of threatened or vulnerable species puts them at risk of impact;
- Important nesting, roosting and foraging areas for sensitive birds and bats;
- Landscape features that concentrate bird or bat movements, such as ridges, escarpments for raptors, or linear features (e.g. rivers, forest edges) for bats;
- Areas along migratory corridors that support high concentrations of birds or bats such as staging areas, stopover sites and 'bottleneck' areas; and
- Other natural features and important sites that people value or depend on for delivery of ecosystem services.

Micro-siting measures for onshore wind farms to date have mainly focused on reducing bird and bat collisions. A prime example of this is the siting of specific 'problem' turbines to reduce the risk of collision mortality. Sensitivity mapping can help to identify any such turbines.

More broadly, the **configuration of turbines** in the wind farm area can be designed to help reduce barriers to bird or bat movement and minimise risk of collision. When there is a clear direction of migration or other movements (e.g. between roosting/nesting and feeding areas), consideration can be given to:

- The minimum distance between turbines;
- Aligning turbines parallel to, and not across, the main bird migration routes or general flight directions;
- Arranging turbines in clusters with corridors between them that provide passage through the site; and
- Considering other wind farms around the project to arrange corridors between farms and projects to provide passage through the site.

Such measures could reduce the risk of collision for birds travelling between roosting, feeding or nesting sites. While these measures are recommended in existing literature,[197] they have been based on inference and limited observation of bird avoidance behaviour at wind farms, and their effectiveness would be hard to quantify. However, these considerations may be more difficult in combination with other considerations like visual assessment and emphasises the importance of optimised site selection (Section 3).

Establishing appropriate avoidance zones around sensitive areas for biodiversity can be implemented with the intention of minimising collision risk and disturbance to at-risk species. Examples include locating wind turbines away from areas of high relief such as ridges and cliff edges, which create an updraft used by soaring bird species. Other landscape features for avoidance include rivers and other water sources, valleys,[198] cave systems,[199] and agricultural areas[200] which can provide sites for roosting, commuting and foraging for bird and bat species. Social experts will need to be consulted to help identify appropriate buffer zones around natural features of high cultural value or dependency by local communities.

In some countries, buffer zones are recommended for individual species or species groups and can be used for guidance.[201] For example, in Portugal, a buffer area around wind farm infrastructure of at least 2 km has been applied to minimise disturbance to known breeding sites of the Iberian wolf (*Canis lupus signatus*).[202] Expert input can help identify appropriate avoidance distances where there is insufficient data or to interpret information from other sources, and apply it to the specific circumstances on site.

Altering wind turbine layouts can help to minimise barriers to species movements and prevent bird collisions. When there is a clear direction to migration or other movements (e.g. between roosting/nesting and feeding areas), turbines can be aligned parallel to this, with corridors left between turbine clusters and wind farms. This is generally believed to provide space for safe passage flight through the site, and thus reduce the risk of collision. While these measures are recommended in existing literature,[203] they have been based on inferences made of bird avoidance behaviour at wind farms.

Re-routing, marking or burying powerlines

Within onshore wind farms, cabling is usually buried, posing relatively little risk to wildlife once installed. However, high voltage transmission lines used to evacuate power from the wind farm can pose a collision risk to some bird species. Transmission lines should, as far as possible, be routed to avoid sensitive areas where there may be high traffic of birds at risk such as near wetlands and waste sites[204] and within bird migration corridors. This is a consideration in early planning, but further re-routing should be considered if more detailed information is available on the presence and movements of at-risk bird species (also Section 8).

Marking transmission lines with bird diverters is now standard good practice, and on average has been shown to halve the numbers of collisions.[205] This may not always be an effective solution for some species or under certain weather conditions, and thus may not be sufficient for risks to species of high conservation concern. For large bats, electrocution risk can be reduced by orienting wires horizontally rather than vertically, as observed in frugivorous bats in Sri Lanka.[206]

Burying power lines poses technical challenges and costs, but is an effective way of avoiding impacts where the lines pass through particularly sensitive

197 For example, van der Winden et al. (2015).
198 Korine et al. (2016).
199 Furey & Racey (2016).
200 Noer et al. (2011); Williams-Guillén & Perfecto (2011).
201 Ferrão da Costa et al. (2018b); Kusak et al. (2016).
202 Ferrão da Costa et al. (2018a).
203 For example van der Winden et al. (2015).
204 Haas et al. (2004).
205 Bernardino et al. (2019).
206 Tella et al. (2020).

areas (e.g. near wetlands and within bird migration corridors)[207] and needs serious consideration in such instances. In some cases, a mix of marking and burying lines may provide the best outcome: for example, collisions with power lines were causing a high mortality of great bustards in Austria and Hungary. When some lines were buried, and others marked with bird diverters, collisions were significantly reduced.[208]

It is recognised that burying of transmission lines could pose risks to biodiversity, particularly during its installation that requires consideration. In certain cases, major earthwork activities could result in the loss of habitat for plants, amphibians and/or reptiles of high conservation concern. It could also disrupt species movement patterns and important linear features, such as rivers, and heighten the risk of invasive species ingress along the disturbed cable route. This measure is therefore a suitable alternative provided it is appropriately risk-assessed. Where transmission lines run above ground, minimisation measures, such as bird diverters, will usually be needed.

In some wind farms, power evacuation may be via medium-voltage lines. If poorly designed, these can pose a significant electrocution risk to many larger birds, especially birds of prey. It is however straightforward (and usually adds little if any cost) to construct safe distribution lines, with insulation and spacing of conductors that eliminate electrocution risk for birds. Detailed guidance may be found in Annex 1.

5.4 Mitigation in the construction phase

5.4.1. Overview

The project construction phase involves preparation of equipment and components, mobilisation of contractors, site preparation works (including land clearance, geophysical investigations and utilities), civil engineering works (including security perimeter fencing, buildings and new or widened access tracks/roads to accommodate large component logistics), construction of electrical infrastructure (including collector transmission cables between wind turbines and substations, transmission lines to connect to the power grid, transformers and the on-site substation), and installation of wind turbines. Off-site grid connections are usually constructed in tandem with on-site works, and typically include upgrades to existing infrastructure or the construction of a new substation to connect to the existing electricity network.

Key *avoidance* and *minimisation* measures at this phase involve consideration of the construction works schedule and implementing physical, operational and abatement controls. Progressive ecological *restoration* of temporary facilities, such as lay-down areas or construction roads, and any proactive conservation actions (PCAs), such as habitat creation or enhancement work (Section 7.2), also need to be planned and implemented throughout construction.

In some cases, opportunities for new mitigation measures, or a more efficient implementation of the mitigation measures, are identified after the project design phase when construction has begun (or during the handover process from design to construction). Thus, minimisation by physical controls at this point involves **modifying the physical design of project infrastructure during construction** to reduce operation-related impacts on biodiversity and ecosystem services. Measures currently recommended mainly focus on **modifications to wind turbines and overhead transmission lines** to reduce risk of bird collisions. Section 8.3 addresses those measures providing mitigation of impacts during the operational phase.

Sometimes, during the construction phase, unforeseen issues can arise that necessitate a change to the project design. This can result in further

207 Bernardino et al. (2018).
208 Ibid.

detrimental impacts to biodiversity and the associated ecosystem services that could trigger a requirement to update the project ESIA, and/or apply for amended consents. It is vital that any such changes are identified as early as possible to enable any additional ecological surveys and assessments required to be completed with minimal disruption to the construction programme.

Good practice mitigation measures for the construction phase are generally applicable to all types of developments, including wind developments, and can help identify appropriate practices to avoid and minimise impacts during project construction.

5.4.2. Avoidance through scheduling

Avoidance through scheduling involves **changing the timing of construction activities** to avoid disturbing species during sensitive periods of their lifecycle. This is the most effective means of construction phase mitigation, and is also an important consideration in avoiding/minimising aggregated and cumulative impacts (Section 3.2).

Construction schedules will need to account for seasonal aggregations (important/essential feeding, breeding and/or migratory periods) and diurnal/nocturnal movement patterns of species of concern. For example, habitat clearance, grading and road construction activities should be scheduled outside species' breeding or hibernation periods. Such activities typically cause the highest noise emission levels early in the construction phase of wind farms.

As with project design, effective avoidance through scheduling requires a good understanding of the seasonal and diurnal activity patterns of sensitive species to be able to identify which key periods to avoid. These may be linked to seasonality in the ecosystem, such as seasonal tree fruiting or forage availability, or the presence of temporary wetlands. Close collaboration between project planners, engineers, environmental specialists and contractors is required to ensure mitigation through project scheduling is effective, as is the implementation of a detailed construction environmental management plan.

5.4.3. Minimisation measures

Minimisation measures in the construction phase can be categorised as:

Operational controls

- Involves managing and regulating contractor activity and movement, including vehicle movement during particularly sensitive periods (e.g. during species migrations through the construction area);
- Locating construction facilities away from sensitive areas, and limiting work vehicles and machinery to designated construction and access areas only;
- Limiting natural vegetation clearance to the minimum necessary during construction works;
- Protecting existing vegetation through establishment of exclusion zones using fencing/barriers;
- Implementing soil erosion and sedimentation control measures;
- Prevent the introduction, movement and spread of invasive species on and off the construction site, for example, by washing vehicles before they enter site;
- Installing sufficient drainage works under all access roads, to reduce freshwater habitat fragmentation, avoid flooding land and damaging nearby waterbodies;
- Ensuring good waste management practices are established in the construction phase, and carried through to the operational phase, to minimise the wind farm's attractiveness to scavenging birds of high collision risk such as vultures; and
- Enforcing good behaviour by construction workers, including prohibition of hunting, trapping, fishing, and general harassment of wild animals.

Abatement controls

- Involving action to reduce emissions and pollutants (dust, light, noise and vibration, solid/liquid waste) that could negatively impact biodiversity and ecosystem services.

5.4.4. Restoration and rehabilitation

Some level of environmental damage is usually inevitable from construction of onshore wind developments, associated with project-related impacts that could not be completed avoided or minimised. Thus, restoration work to repair this damage will be required. For areas of temporary project footprint, sensitive reinstatement to enable habitat to recover to its original condition and function should be undertaken in a phased approach concurrent with construction activities. 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.

Onshore wind farm developments, particularly those located on degraded lands, such as agricultural areas, are encouraged to take further steps to employ PCAs (Section 7.2) to enhance the habitat on site to create benefits for biodiversity.

5.5 Mitigation in the operational phase

5.5.1. Overview

Once commissioned, an onshore wind farm is expected to operate continuously for the turbine's lifespan of up to 40 years. Electricity generated by the wind farm is sold to customers, and the income used for loan repayment, operational and maintenance staff salaries, utility charges, landowners rent, local authority rates, project insurances, mitigation and offset measures etc.

Onshore wind farms generally have low maintenance and servicing requirements. Scheduled maintenance is undertaken at regular intervals to minimise the effects of degradation on wind turbines and civil and electrical infrastructure. Unscheduled maintenance is also conducted when issues or failures arise.

Minimisation measures in the operational phase involve implementing physical and abatement controls (or *operational controls*). Commissioning of wind turbines is often a rolling process with individual turbines, or groups of turbines, installed and commissioned as the construction phase progresses. This means operational mitigation measures need to be in place, at the appropriate scale, from the commissioning of the first turbine (i.e. as soon as turbine blades begin rotating).

5.5.2. Minimisation measures

Minimisation in the operational phase of an onshore wind farm can be categorised as:

- Minimisation by **physical controls:**
  - Involves modification to standard infrastructure, or the standard operation of infrastructure, to reduce impacts on biodiversity;
- Minimisation by **abatement controls:**
  - Involves action to reduce emissions and pollutants (dust, light, noise and vibration, solid/liquid waste) that could negatively impact biodiversity and ecosystem services;
- Minimisation by **operational controls**:
  - Involves managing and regulating activity and movement of operations and maintenance contractors and land managers.

Physical controls

Collision risk

A primary biodiversity risk during the operational phase is the potential for birds and bats to collide with turbine blades or overhead powerlines. The most effective measure is to shut down turbines temporarily when species of concern are at risk. This could be specified for pre-defined periods, and could comprise some or all of the following:

- **Time of the day/night**, for example time of species peak diurnal activity;
- **Ambient environmental factors**, for example wind speeds and temperature, which are particularly relevant for bats; or
- **Seasonal**, for example during bird/bat migration seasons.

Alternatively, or additionally, turbine shutdown could be 'on demand' in real time, in response to a pre-determined set of criteria based on the potential occurrence of high-risk scenarios, for example large flocks of priority bird species spotted approaching a wind farm.

Where priority species are only present around turbines during clearly demarcated periods or conditions, pre-defined shutdown for these periods will effectively avoid impacts.[209] For example, shutdown can occur for migratory birds that travel through a wind farm in predictable pulses. This approach also requires minimal on-going surveillance on-site. However, it may often have relatively high economic cost through loss of power generation.

Where species presence is less predictable, real-time shut-down on demand is likely to be a more practical approach.[210] Shut-down on demand is likely to reduce but not completely prevent impacts. There may also be significant on-going surveillance costs, for staff and/or equipment.

Shut-down on demand approaches for birds

Shut down 'on demand' (SDOD) is based on real-time observations of bird activity in the wind farm area. SDOD approaches for birds rely on one or more of the following: (i) field observers; (ii) image-based systems; and (iii) radar systems.[211]

Observer-led SDOD requires experienced bird field surveyors to be stationed at vantage points within and in the vicinity of the wind development area. Using pre-established criteria, observers identify priority bird species and track their flight path. If a collision appears likely, observers notify the wind farm control centre to have the 'risk turbine(s)' immediately shut down. The turbine(s) will only be re-started when the risk of collision has passed.

The number and location of observers must be adequate to allow 'at-risk' birds to be detected and identified in good time, so that turbines can be stopped before the birds reach them. The requirements will vary for different wind farms depending on size, turbine layout, as well as the size, flight speed and flight direction of priority species. This approach may not be appropriate for some priority species if they are too small or if flight is too fast for them to be identified in time for turbines to shut down before individuals enter the collision risk zone (Annex 2, case study 13).

Image-based systems use cameras to capture digital still images or video sequences of birds, while **radar systems** identify flying animals, distinguished roughly by size, based on echo characteristics and/or wing beat frequencies (Table 5-3). These systems can be paired with automated analysis of the images by a computer software. Operators can activate shutdown after receiving for real-time information from the system or alternatively an automated shutdown by the system itself.

Owing to current technological limitations, it will usually be advisable to support image-based and radar systems with human observers. For example, radar systems can only distinguish object-size

209 BirdLife International (2015); Tomé et al. (2017).
210 BirdLife International (2015); Tomé et al. (2017).
211 BirdLife International (2015).

classes rather than species and not between species or species-groups of interest, unless their size is different from all other species present. Furthermore, the effectiveness of technology to support SDOD procedures is still unproven. Further details of each system, including their advantages and disadvantages, is presented in a number of resources listed in Annex 1. Table 5-4 presents some examples of automated image detection and radar technologies for SDOD.[212]

Mitigation approaches for bats

There is substantial evidence that insectivorous bat activity around wind turbines and associated collision fatalities are highest at low wind speeds.[213] An effective minimisation measure is thus to increase the wind speed at which turbines become operational (the 'cut-in speed'). Below this speed, depending on the model, turbine blades are either stopped from rotating, or 'feathered' (pitched parallel with the wind direction), spinning very slowly, if at all, with no energy output.

Relationships between bat activity and weather parameters may differ between species, sites and years. Thresholds for turbine cut-in speeds thus need to be based on site-specific monitoring results. Cut-in speeds can be adjusted for site-specific bat activity peaks considering a number of parameters (Annex 2, case study 3):

- Wind speed (m/s measured at nacelle height);
- Time after sunset/before sunrise;
- Month of the year;
- Ambient temperature; and
- Precipitation (mm per hour).

Either increasing cut-in speeds, stopping/feathering blades, or both, are proven to reduce bat fatalities. Studies in North America[214] and Europe[215] showed that applying these measures resulted in at least 50% reductions in bat fatalities. Resulting power losses and economic costs were revealed to be low, resulting in as little as a 1% decrease in total annual output.[216]

These measures do not apply to non-echolocating plant-visiting bats. While evidence shows that certain species could be vulnerable to colliding with wind turbines,[217] there is no empirical evidence for mitigation measures that are proven effective in minimising plant-visiting bat fatalities during operation. Additional studies in the future may help identify new measures to reduce collision risk of this group during the operational phase.

Other approaches to reduce collision risk

Other measures recommended mainly focus on **modifications to wind turbines and overhead transmission lines** to reduce risk of bird and bat collisions (summarised in Table 5-2), including:

- Painting one turbine blade to increase visibility to birds;
- Using ADDs;
- Installing bird flight diverters on overhead powerlines (Table 5-3);
- Wildlife-safe design or retrofitting power-line wires and poles; and
- Altering the configuration of overhead powerlines to increase visibility to birds.

Other measures have been proposed but do not appear to be as effective and/or have associated unpredictable effects.[218] These include:

- Auditory deterrents for birds such as warning sirens. This approach is being trialled with the DTBird system (Table 5-3), and while trial results are promising for some species in some locations, this method has yet to be demonstrated as generally effective for a broad range of species and sites. The loud noise, audible to

212 This list is not meant to be exhaustive or imply endorsement, and many other technologies exist or are being developed.
213 For example, Voigt et al. (2015).
214 Arnett et al. (2011; 2013); Baerwald et al. (2009).
215 Rodrigues et al. (2015).
216 Arnett et al. (2013).
217 Arnett et al. (2016).
218 Arnett & May (2016); Drewitt & Langston (2006); Marques et al. (2014).

humans, of this mitigation method means it may have limited deployment opportunities;

- Visual deterrents such as lasers;
- Other measures that aim to increase turbine visibility, including markings on the ground and some turbine blade patterns (square-wave and black-and-white bands) and use of ultraviolet reflective paint; and
- Adjusting the frequency, colour or wavelength of flashing aviation lights on turbines.

Additional studies in the future may find these measures to be effective for other, specific species, or identify new measures to reduce collision risk.

Table 5-2 Summary of other mitigation measures recommended for minimising bird and bat collisions at operational onshore wind farms

Mitigation measure	Receptor	Description	Examples evidencing effectiveness
Wind turbines			
Increasing visibility of rotor blades	Bird	This measure involves painting one of the three turbine blades, thus reducing visual 'smear'[219] and making it easier for birds of prey to detect the rotating blades. Initial evidence for the effectiveness of this measure from one study on one species is promising. There may also be regulatory, engineering and societal constraints to apply this measure.	Painting two-thirds of a single blade of each wind turbine black in colour in the Smøla wind farm in Norway reduced white-tailed eagle (*Haliaetus albicilla*) fatalities by 100% over unpainted controls.[220]
Installation of acoustic deterrent devices	Bat	This measure involves the installation of acoustic devices on the turbines. These devices emit high frequency sounds within the range of bat call frequencies to mask echo perception, or create an airspace around the rotor swept area that bats might avoid. Evidence of the effectiveness of this measure is limited to North America to date, but is currently being trialled elsewhere.	At Los Vientos wind farm (Texas, USA) acoustic devices resulted in a 50% reduction in overall bat fatalities with varying species-specific responses. There was a 54% and 78% reduction in fatalities for the Brazilian free-tailed bat (*Tadarida brasiliensis*) and hoary bat (*Lasiurus cinereus*), respectively. Species-specific differences may be linked to differences in echolocation frequencies. Acoustic devices appeared to be less effective for bats with high frequency calls.[221]
Overhead power lines			
Installation of bird flight diverters	Bird	Attaching devices (typically flappers, balls or spirals) to transmission lines to increase their visibility. Evidence for the effectiveness of this measure is fairly robust. Table 5-3 summarises the different design options and examples of effective application.	An analysis of 35 studies on the effectiveness of wire-marking in reducing bird collisions with power lines revealed that average collision mortalities was reduced by 50%, with the type of device having no influence on this effect.[222]
Wildlife-safe design or retrofitting power-line wires and poles	Bird	Designing low- or medium-voltage power lines, or adding insulation to existing poles and wires, to reduce the risk of electrocution of birds or other wildlife from contact. Evidence proving the effectiveness of this measure is robust, although ongoing maintenance may be required if components have a limited life.	In Mongolia, retrofitting of insulation on low-voltage power pylons resulted in an estimated 85% reduction in mortalities.[223]
Altering transmission line configurations	Bird and bat	Measures to change the design of transmission lines to reduce bird collisions aim to reduce the vertical spread of lines, increase the visibility of lines, and/or decrease the span length. Specific measures could include: (i) reducing the number of vertical wire levels by adjusting the conductor heights to reduce the number of potential collision points; (ii) stringing wires as low as possible; (iii) keeping wire span lengths as short as possible to minimise line height as birds usually respond to seeing lines by increasing height; and (iii) using wires with a thicker diameter or bundling wires to increase visibility.	While these measures are generally agreed upon and recommended, further scientific evidence is needed to clearly demonstrate their effectiveness.[224] Electrocution risk to fruit bats was found to be almost zero for powerlines with wires oriented horizontally. Vertically-oriented powerlines killed close to one individual per km of powerline.[225]

219 Hodos (2003); Hodos et al. (2001).
220 May et al. (2020).
221 Weaver (2019).
222 Bernardino et al. (2019).
223 Dixon et al. (2018).
224 Bernardino et al. (2018).
225 Tella et al. (2020).

Table 5-3 Selected examples of automated image detection and radar technologies for shutdown-on-demand*

Technology	Application	Demonstrated use & effectiveness
Camera technology		
DTBird Uses a suite of daylight and/or thermal imaging cameras mounted on individual turbines or similar structures	**Birds only** Once targets are identified, the system can issue a warning sound or automatically shut down turbines, based on preset criteria (e.g. distance from turbine). Detection distance is related to bird size. Best-case scenario for a golden eagle (*Aquila chrysaetos)* is ~600 m during the day and ~200 m at night.	Detectability was shown to be >80% at a test site in California, USA.[226] Warning sounds reduced flights in the collision risk zone in trials in Sweden and Switzerland by 38-60%.[227]
IdentiFlight Uses a suite of daylight and/or thermal imaging cameras mounted on individual turbines or similar structures	**Birds only** Imaging is linked to an algorithm to classify objects; has the potential to be species-specific. Fully integrated with Supervisory Control And Data Acquisition (SCADA) for automated shut down; no need for human involvement. Has an operational range of 1,000 m.	Has a 96% detection rate (i.e. missed 4% of all bird flights) with a false negative rate of 6% (classifying eagles as non-eagles) and false positive rate of 28% during trials in Wyoming, USA.[228] Installed at wind farm sites in Australia (for wedge-tailed and white-tailed sea eagles), northern Germany (for red kites) and multiple USA sites.
Radar technology		
Robin Radar Max © Uses radar to provide real-time detection and 3D tracking of birds	**Birds only** Has a ~15 km maximum detection distance with unrestricted line of sight. Shut down can be fully automated using predefined rules, and has the potential to be species-specific. Expensive to purchase, at ~ >US$ 500,000. Use may be restricted by national military or aviation regulations.	Deployed at the Tahkoluoto offshore wind farm in Finland, to prevent collisions from white-tailed sea eagles and black-backed gull.[229] Operational at the Kavarna wind farms in Bulgaria, where it automatically shuts down turbines for priority species, particularly migratory species.
STRIX BirdTrack A radar system to automatically detect and track individual birds or bats	**Birds and bats** Cannot identify individual species – can detect size class only. Has a detection range of up to 12 km, depending on target size. Shut down can be fully automated using predefined rules or manually controlled. Radar use may be restricted by national military or aviation regulations. Has not been used in isolation, always in combination with observers.	BirdTrack was used at the Barão de São João wind farm (Annex 2, case study 13) with zero fatalities over five years (note: radar was used in combination with observers). Deployment in Egypt has resulted in fatality levels held at 5–7 fatalities, from around 370,000 birds passing through the wind farm each season.[230]

** Note: This list is not exhaustive. Other technologies are available and in the process of development.*

226 H.T. Harvey & Associates (2018).
227 Riopérez et al. (2016).
228 McClure et al. (2018).
229 Södersved (2018).
230 Tomé et al. (2018).

Table 5-4 Bird flight diverter designs

Design	Practical and ecological considerations	Evidence of effectiveness
Flappers (mobile)	Come in a wide variety of sizes and configurations – all of which have similar levels of effect. Very visible because they can pivot over 360° when windy, and some contain reflective panels or iridescent components making them visible at night. May malfunction (either break or fall off) in locations with sustained high wind speeds or extreme temperature conditions. Can be installed on operational transmission lines using drones, or from the ground using a hot stick.	In California, installation of flappers on spans reduced avian collisions by 60% when compared with non-marked spans.[231] In Nebraska, installation of flappers resulted in >50% reduction in sandhill crane deaths compared to spans without flappers.[232]
Spirals (static)	Come in a variety of dimensions for different line widths. Likely the most durable option, with no moving parts, but may be less visible to some species for the same reason. Very challenging to install once transmission line is operational, and installation is labour-intensive. Not recommended for installation on transmission lines >230 kV due to corona effects.	In Indiana, waterfowl collisions were reduced by 73% and 37.5% for small and large spirals, respectively, on marked versus unmarked lines.[233] In the UK, installation of large spirals reduced average springtime collisions from c. 15 to <1 mute swan between years.[234]
Night-lit devices	Important where at-risk species move by night. New technology which has only been trialled in a limited number of sites for a few species; effectiveness unknown for other species or locations.	Installation of near-ultraviolet lighting that shines on powerlines in Nebraska, USA reduced sandhill crane (*Antigone canadensis*) collisions by 98%.[235] In South Africa and Botswana bird flapper and flight diverters fitted with Light Emitting Diodes (LED) have been installed to reduce flamingo (*Phoenicopterus roseus* and *P. minor*) and blue crane (*Anthropoides paradiseus*) collisions. Anecdotal evidence points to the effectiveness of this mitigation measure.[236]
Aviation balls	May not be suitable for areas where ice or high winds are expected, due to increased stress on the line. Visually more obvious than other options. More costly per unit than other options, but greater spacing means overall costs may not be more costly. Labour-intensive to install on existing line. Use may be limited by aviation regulations.	Installation of 30 cm diameter yellow balls with a black stripe on spans in Nebraska reduced collisions of sandhill cranes by 66% compared with unmarked spans.[237] In South Carolina, there was a 53% reduction in all species' collision mortalities at spans with yellow balls compared with unmarked spans.[238]
Increasing wire thickness	Much more expensive than standard diameter wire, and requires heavier-duty supporting infrastructure. Extremely durable, with quoted life-spans of >40 years.	Anecdotal evidence of effectiveness, but unproven in rigorous field trials.

231 Yee (2008).
232 Murphy et al. (2009).
233 Crowder (2000).
234 Frost (2008).
235 Dwyer et al. (2019).
236 Smallie (2008); van Rooyen & Froneman (2013).
237 Morkill & Anderson (1991).
238 Savereno et al. (1996).

Abatement controls

Minimisation through **abatement** includes controls to reduce impacts from light, noise and accidental chemical spill or leaks, as well as ensuring that there is a protocol for rapid response and management of any such incidents.

In general, good environmental practices will need to be implemented during wind farm operation. Annex 1 summarises a list of good practice guidance documents to serve as a reference when developing the environmental practices to be applied during construction.

Operational controls

Existing operational control measures recommended to date are specific to raptors, and relate to **land management measures**, and **minimising food resources and availability**. Land management measures relate to establishing or altering vegetation and habitat conditions to reduce suitable foraging and nesting habitat (Annex 2, case study 24). Evidence for the success of these measures is relatively unproven at the moment and success is likely for only raptor species with specific habitat preferences, although some examples exist. As regards red kites in Germany, controlling agricultural management activities within the site, such as no mowing before mid-July and reducing the attractiveness of habitat in the surrounding area, has been recommended to minimise collisions.[239]

Minimising food resources and availability involve scaling back conditions for suitable habitat for raptor prey on site, removal of rock piles, brush piles and snags to reduce small mammal availability for foraging raptors, tilling soil to reduce suitability for preferred prey, or the removal of carcasses to avoid attraction of large numbers of scavenger species such as vultures (Annex 2, case study 26).[240] Off-site habitat enhancement can also help divert raptors away from wind farms.[241] Common approaches include:

- Provision of diversionary/supplementary feeding stations;[242]
- Promoting increase of prey or food availability through habitat management;[243] and
- Creating suitable roosting, breeding or feeding areas away from the wind farm.[244]

Similarly, for bats, establishing new off-site fallows and hedgerows as foraging areas and bat-boxes,[245] as well as the restoration of off-site roosting habitat, may reduce the number of bats in the wind farm area, thus lowering collision risk.[246]

It is also important that good behaviour by contractors is enforced, including prohibition of hunting, trapping, fishing and general harassment of wild animals.

Lastly, measures to minimise the potential for vehicle collision with fauna should also be considered, including:

- Limiting the number of vehicle movements to and from the wind farm;
- Restricting vehicles to authorised routes/roads; and
- Limiting vehicle speed on site.

239 Mammen et al. (2011).
240 Martin et al. (2012); Pescador et al. (2019).
241 Gartman et al. (2016).
242 Cortés-Avizanda et al. (2016); Gilbert et al. (2007); Martínez-Abraín et al. (2012).
243 Paula et al. (2011).
244 Gartman et al. (2016); Walker et al. (2005).
245 Millon et al. (2015).
246 Gartman et al. (2016).

5.6 End-of-life

5.6.1. Overview

At the end of the designed operational life of an offshore wind farm, broadly, the options are to: (i) extend the operational life of the existing assets; (ii) repower the site (Section 5.6.3); or (iii) fully decommission the site.[247] Both repowering and decommissioning provide opportunities to undertake further mitigation and are the focus of this section.

5.6.2. Repowering

Other than the options of decommissioning and end-of-life extension, **repowering** is the other option that can be taken for wind farms facing the end of their operational lifespan. Repowering can be undertaken by either completely replacing older wind turbines or changing out parts in the original turbines with new, more efficient technologies to capitalise on the existing wind resource areas, and may extend turbine operational life by up to 20 years.[248]

With rapid technological advancements in recent years, older or obsolete wind turbines are typically replaced with fewer, more efficient and higher capacity models that are generally larger and taller. To accommodate the changes, these new turbines will need to be re-sited and new foundations constructed. Depending on the extent of the design changes, it is likely to result in alterations and requirements to the civil and electrical infrastructure such as wider roads and larger turbine foundations.

Repowering brings the project back to the **start of its life-cycle process**, and is an opportunity to reduce existing biodiversity and associated ecosystem service impacts, especially where fatalities are known to occur for species of concern. Section 5.3, 5.4 and 5.5 addresses mitigation measures that should be re-considered at this phase.

Avoidance through project design

Recent trends see a shift towards taller turbines that have larger rotor swept zones and are further apart from each other. Despite their larger blades, these modern turbines usually have a lower collision rate per MW for birds than older, smaller ones.[249] However, they may pose a new risk for certain groups, such as large migratory soaring birds and open-air foraging bats, which previously flew above the rotor swept zone of smaller turbines. Repowering projects need to reassess their risks, in case they may cause impacts on new species.

Repowering provides the opportunity to more carefully site new wind turbines to minimise collision risk, which can lead to significantly fewer collisions.[250] Applying this mitigation measure effectively at this phase will require existing fatality monitoring data of sufficient duration and extent (see Section 8 for more information on approaches to good practice monitoring). This will enable an understanding of the association between landscape features and old 'problem turbines' or associated facilities that are causing a disproportionate number of fatalities. Section 5.3 covers mitigation measures related to changes to the siting of project infrastructure.

5.6.3. Decommissioning

The decision to decommission could be driven in part by the onshore wind farm site lease, depending on land ownership considerations. Decommissioning is the removal or making safe of onshore wind farm infrastructure at the end of its useful life.

The decommissioning phase involves the dismantling and removal[251] of wind farm infrastructure and associated facilities, such as turbines and their foundations, transformer, roads or tracks, buildings, substation and cables, at the end of a wind farm's operating life.

247 BVG Associates (2019).
248 GE Renewable Energy (2020).
249 Barclay et al. (2007); Dahl et al. (2015); Smallwood & Karas (2009).
250 Dahl et al. (2015).
251 If legislation allows, consideration should be made as to whether removal of any infrastructure would be more detrimental to biodiversity than leaving it place.

Avoidance and minimisation

Decommissioning is essentially the reverse of the construction phase, employing many of the same procedures and equipment used during construction. Hence, as in the construction phase, avoidance through scheduling (Section 5.4.2) and minimisation by operational and abatement controls (Section 5.4.3) will also generally apply here. Some of the considerations include:

- **Reviewing** the monitoring dataset accumulated over the project lifecycle and undertaking field surveys, if needed, to confirm the sensitive species for consideration during decommissioning (monitoring for shut-down on demand is likely to have generated large datasets on the abundance of species);
- **Avoiding** decommissioning work during sensitive periods of species' lifecycles. Scheduling will need to account for seasonal aggregations such as critical breeding and/or migratory periods and diurnal/nocturnal movement patterns, and requires a good understanding of the seasonal and diurnal activity patterns of sensitive species to identify key periods to avoid. Such avoidance periods may be linked to seasonality in the ecosystem, such as seasonal tree fruiting or forage availability, or the presence of temporary wetlands;
- **Minimising** habitat disturbance during foundation removal;
- **Minimising** noise impacts on fauna associated with infrastructure removal procedures;
- Accounting for and addressing potential social and ecosystem service impacts arising from biodiversity mitigation;
- **Managing** waste disposal and implementing a protocol for rapid management of any chemical leaks or spills;
- **Ensuring** good practice for reuse, recycling or disposal of decommissioned components; and
- **Enforcing** good behaviour by decommissioning workers, including prohibition of hunting, trapping, fishing and general harassment of wild animals.

All mitigation measures should be captured in a detailed decommissioning plan or a similar arrangement.

Restoration

After decommissioning, the site should be reinstated to its original state and, as far as possible, in accordance with national requirements and/or land lease agreements made with land owners, in consideration of the ecological status of the site at the time of decommissioning. The end-of-life wind farm infrastructure components including steel towers, blades and aluminium, and copper cables, will need to be recycled or otherwise disposed of responsibly. Restoration measures (Section 5.4.4) following good environmental practices should be the focus during this phase and included in the decommissioning plan.

Decommissioning onshore wind farms is not dissimilar to other onshore power generation facilities, such as mining and oil and gas, as they share similar civil and electrical infrastructural components. Hence, good practice mitigation measures applicable to many types of onshore developments will be relevant.

5.7 Summary of mitigation approaches for onshore wind

Table 5-5 summarises the mitigation approaches addressed in this chapter for onshore wind.

Table 5-5 Summary of mitigation approaches for onshore wind farm development

Project phase	Mitigation Hierarchy	Mitigation approaches include:
Project design phase	Avoidance and Minimisation	Micro-siting: changing the layout of project infrastructure to avoid sensitive habitats or areas used by sensitive species Re-routing, marking or burying onshore powerlines to avoid collision risk
Construction phase	Avoidance	Scheduling: changing the timing of construction activities to avoid disturbing biodiversity during sensitive periods
	Minimisation	Abatement controls to reduce emissions and pollutants (noise, erosion, waste) Operational controls to manage and regulate contractor activity (e.g. exclusion fencing around sensitive areas, designated machinery and lay-down areas)
	Restoration and rehabilitation	Revegetation of temporary use areas as they come available, using top soil and indigenous plants from the site where possible
Operational phase	Minimisation	Physical controls: modification to infrastructure, or its operation, to reduce impacts (e.g. shutdown on demand to minimise collision risk, installation of Bird Flight Diverters on transmission lines) Abatement controls (e.g. restricting vehicle movements when sensitive species are present, waste management) Operational controls to make sites less suitable for sensitive species (e.g. habitat modification, removal of carcasses for scavengers)
End-of-life	Avoidance	Scheduling: changing the timing of decommissioning activities to avoid disturbing biodiversity during sensitive periods (e.g. during breeding seasons)
	Minimisation	Abatement controls to reduce emissions and pollutants (e.g. noise, erosion, waste) created during decommissioning Operational controls to manage and regulate contractor activity (e.g. exclusion fencing around sensitive areas, designated machinery and lay-down areas)
	Restoration and rehabilitation	Revegetation of disturbed areas as they become available, using top soil and indigenous plants from the site where possible. Reinstatement of original vegetation, as far as feasible, after decommissioning Consider (if legislation allows) if leaving infrastructure would provide benefits to sensitive species

6. Offshore wind energy – Potential impacts and mitigation approaches

6.1 Overview of offshore wind development

This chapter presents an overview of the primary biodiversity and ecosystem service impacts of fixed offshore wind turbine structures, followed by discussion of the key mitigation approaches that can be employed at each project stage (design, construction, operation and end-of-life).

There are currently two main types of offshore wind technology: i) bottom fixed foundation turbines (the most prevalent type at present); and ii) floating turbines. Bottom fixed turbines are generally installed in water depths up to approximately 60 m. They have underwater structures (usually monopiles, tripods or jackets) fixed to the seabed via a foundation piece (common types include monopiles or multipiles, gravity bases and suction-caissons). In deeper waters, the feasibility of installing fixed foundations decreases, and floating turbines anchored to the seabed may be used instead (Box 10).

A typical fixed offshore wind turbine structure comprises components both above (the nacelle, rotor, blades and tower) and below (the sub-structure, foundations and scour protection material) the water. In addition to the individual wind turbines, the primary components of an offshore wind farm development include:

- Offshore:
  - substation; and
  - buried cables (inter-array and export).
- Onshore:
  - construction port;
  - onshore substation;
  - buried export cable; and
  - transmission lines.

Figure 6.1 Overview of key project components of an offshore wind development

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6.2 Impacts of offshore wind energy on biodiversity and ecosystem services

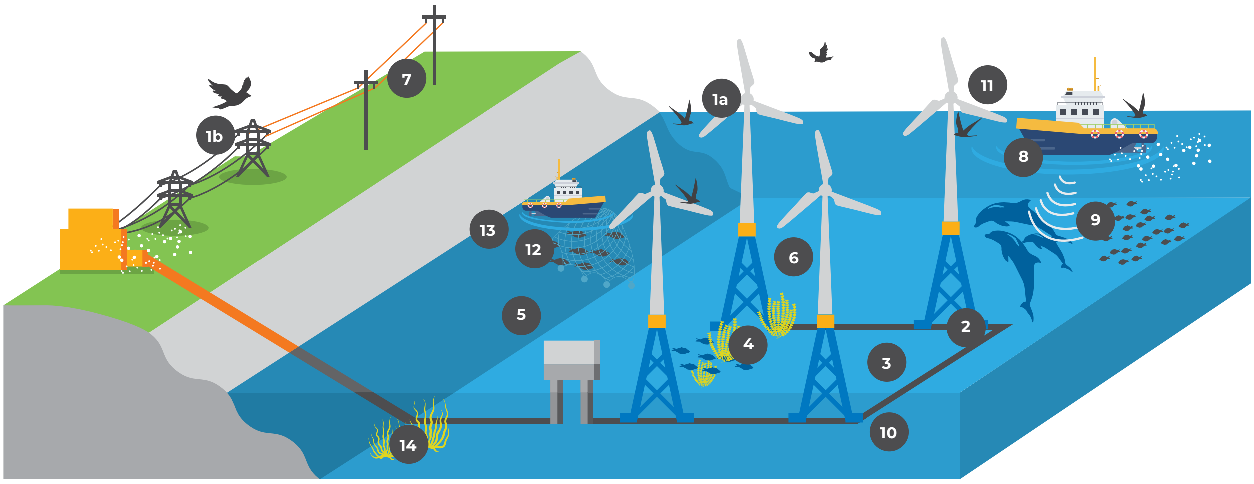
6.2.1. Summary of key impacts

The available scientific literature agrees on the key impacts of offshore wind: i) risk of collision mortality; ii) displacement due to disturbance (including noise impacts); iii) barrier effects (also including noise impacts); iv habitat loss; and v) indirect ecosystem-level effects.[252] There is still much to understand on these five key impacts – but it is clear that that they must be considered carefully in all stages of offshore wind farm planning and development. The broad approach to undertaking an impact assessment for onshore wind energy is often equally relevant to offshore wind projects.

There is also evidence that in some circumstances offshore wind farms can have positive biodiversity impacts (case study 1), including introduction of new habitat, artificial reef effects and a fishery 'reserve effect' where marine fauna tend to aggregate due to the exclusion of fishing (Section 7.2.1).[253] However, it should be noted that this may in turn lead to an increased attraction of foraging seabirds to the wind farm area.[254]

Table 6-1 summarises the key biodiversity impacts of offshore wind farm development, with selected references.

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



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

252 Perrow (2019).
253 Bergström et al. (2013); Langhamer (2012); Perrow (2019); Wilhelmsson et al. (2010); Emerging Technology (2017).
254 Cook et al. (2014); Skov et al. (2018); Walls et al. (2013); Welcker & Nehls (2016).

Table 6-1 Summary of the key biodiversity and associated ecosystem service impacts of offshore wind developments. The significance of particular potential impacts will be context-specific

No.	Impact type	Project stage	Description
1	**Bird and bat mortality from colliding with turbine blades and/or onshore transmission lines**	Operation	Birds flying in the turbine rotor swept zone are potentially at risk of collision and serious injury or death[255] (e.g. migratory birds passing through the wind farm area, or birds in the area to forage/hunt for prey). The percentage of time spent flying at collision risk height is key,[256] as is an understanding of species-specific avoidance behaviour.[257] Nocturnal migrant passerines are also at risk of collision, since they can be drawn to the nacelle lights.[258] Bats are also potentially at risk of collision and possibly barotrauma. While barotrauma (injury caused by sudden pressure changes around the moving blades) was initially hypothesised as a major source of bat mortality at onshore wind turbines,[259] there is little empirical evidence for this. Very little is known about the potential impacts of offshore wind farms on bats, although there are some empirical studies/observations. A good summary of the risk to bats from offshore wind farms is given in a recent review.[260] Bats have been shown to forage within wind farms and other offshore installations,[261] and studies have shown foraging at sea, for example between 2.2 km and 21.9 km[262] from the coast. Bats may also be attracted to offshore wind turbines, potentially by lighting.[263] While there is little information on flight altitudes of bats on migration, and on behaviour of bats at operational offshore wind farms,[264] there is sufficient evidence to suggest that many species migrate offshore and use islands, ships and other offshore structures as opportunistic/deliberate stopovers.[265] The characteristics of offshore migration of bats are well summarised in a recent review.[266] Onshore, there is potential for collisions with the (thin and hard to see) earth wire of transmission lines, which may lead to significant fatalities for some species such as bustards.[267]
2	**Seabed habitat loss, degradation and transformation (bottom-fixed turbines)**	Construction/ operation	Areas of benthic habitat may be lost completely under the foundation or degraded due to construction activity (causing sediment plumes and smothering), displacing benthic organisms permanently or temporarily. The total area lost is, however, generally tiny in relative terms.[268] There may also be impacts associated with lighting and vibration associated with construction, such as cable trenching remote-operated vehicles and foundation installation. Installation of foundations, scour protection and turbine towers can also have hydrodynamic effects that alter the demersal habitat or change water column conditions (see row no. 3).

255 Desholm & Kahlert (2005); R. W. Furness et al. (2013); Humphreys et al. (2015).
256 King (2019).
257 Skov et al. (2018).
258 BirdLife International (n.d.).
259 Baerwald et al. (2008).
260 Hüppop et al. (2019).
261 Ibid.
262 Sjollema et al. (2014).
263 Rydell & Wickman (2015).
264 Ahlén et al. (2007); Hüppop et al. (2019); Lagerveld et al. (2017).
265 Hüppop et al. (2019).
266 Ibid.
267 Mahood et al. (2017).
268 Perrow (2019).

3	**Hydrodynamic change (bottom-fixed turbines)**	Operation	The installation of foundations, scour protection and turbine towers can change hydrodynamic conditions, potentially affecting benthic communities and fish species.[269] Effects may be negative (e.g. scour around turbines, increased turbidity and smothering) or positive, through habitat creation (see row no. 4). Although impacts of wind turbines on the upper ocean is not yet well understood, turbines can disturb downwind wind fields by decreasing wind speed and increasing turbulence. Wind-wake effects can cause both upwelling and downwelling, potentially affecting an area 10–20 times larger than the wind farm itself, with possible knock-on ecosystem effects.[270]
4	**Habitat creation (including reef and refuge effects associated with bottom-fixed turbines)**	Operation	The new hard substrate introduced in turbine foundations, scour protection and turbine towers can create new habitat for colonisation by benthic organisms (case study 17). Turbine bases also often appear to provide a refuge for fish.[271] A typical offshore wind turbine can support up to four metric tonnes of shellfish,[272] which might be expected to attract a range of other organisms to the wind farm area. The initial colonisation of species within lower trophic levels is quickly followed by larger invertebrates, such as crabs and lobsters and small fish, thereby attracting larger predatory fish.[273] Such alteration of the local biodiversity status could have a positive ecosystem services influence in terms of biodiversity, tourism and fisheries effects.[274] The exclusion of fisheries from the offshore wind farm area, which may or may not be regulatory – depending on the jurisdiction – can offer refuge and shelter for both benthic communities and fish. A review of offshore wind power for marine conservation concluded that offshore wind farms can be at least as effective as existing marine protected areas in terms of creating refuges for benthic habitats, benthos, fish and marine mammals.[275]
5	**Trophic cascades**	Operation	Changes in benthic habitat and hydrodynamic conditions, and new habitat creation associated with the offshore wind farm (see row no. 4), have the potential to affect species abundance and community composition, and therefore affect predator-prey dynamics around an operational offshore wind farm. This is likely to be a greater risk to fixed-bottom compared to floating turbines. Evidence shows that important changes to the fish community structure and the trophic interactions within the local marine ecosystem occur where fish are attracted to the wind farm (in turn attracting foraging birds and marine mammals to the wind farm area). [276] A Dutch study found more porpoise activity in the operational wind farm area in reference areas outside the wind farm, which is most likely linked to the increased food availability, exclusion of fisheries and reduced vessel traffic.[277] A study on wind farms in the Bay of Seine, France showed that higher trophic levels including some fish, marine mammals and seabirds responded positively to the aggregation of biomass on wind farm structures, and that total ecosystem activity increased after construction of the wind farm,[278] although these wind farm effects on the coastal trophic web are considered as limited. The effect of trophic cascades may become more apparent with long-term monitoring.

269 ICES (2012).
270 Boström et al. (2019).
271 Bergström et al. (2013); Langhamer (2012); Wilhelmsson et al. (2010).
272 Emerging Technology (2017).
273 Gill & Wilhelmsson (2019).
274 Soukissian et al. (2017).
275 Hammar et al. (2015).
276 Gill & Wilhelmsson (2019).
277 Lindeboom et al. (2011).
278 Raoux et al. (2017).

6	**Barrier effects or displacement effects due to presence of wind farm (bottom-fixed turbines)**	Construction/ operation	Barrier and displacement effects[279] arise where the wind farm presents an obstacle to regular movements to and from breeding colonies or migration routes, or deters species (birds, marine mammals, turtles and fish) from regular use of the wind farm area. Whilst there are few supporting empirical studies, the variation in observed displacement levels for different seabird species is hypothesised to be due to several factors, including habitat quality, prey distribution and wind farm location relative to the colony/feeding grounds.[280] Models show that red-throated divers (*Gavia stellate***)**, for example, may experience displacement effects up to 15 km from the wind farm.[281] Telemetry studies of guillemots (*Uria aalge*) also show avoidance behaviour during the breeding season.[282] The effect of barrier and displacement is hard to quantify (manifested through impacts on daily time and energy budgets, which may ultimately reduce demographic fitness), and the two may be difficult to differentiate.[283] The impact on birds may vary spatiotemporally due to habituation and cumulative effect of other wind farms.[284] Conversely, some foraging seabirds have been noted to be attracted to wind farm areas[285] (and see habitat creation and trophic cascades above in this table). Bats' response to turbines differs across species and locations. Very little is known about the potential impacts of offshore wind farms on bats, although there are some empirical studies/observations (see row no.1).
7	**Bird and bat mortality through electrocution on associated onshore distribution lines**	Operation	With respect to the onshore facilities associated with an offshore wind farm, electrocution rates on the pylons of low- or medium-voltage lines can be high and disproportionately affect some species that use low-voltage pylons as perches when hunting or nesting. Electrocutions may be partially responsible for the decline of some long-lived species, and are rarely significant on high-voltage transmission lines.[286] In developed countries with better-developed electricity/grid facilities, offshore wind developments are likely to connect into existing transmission/ distribution facilities. However, in emerging markets, the onshore grid facilities may need to be constructed from scratch. There is limited evidence of risks to bats, although electrocution of large bat species, particularly fruit bats, has been identified as an issue associated with distribution lines.[287]
8	**Mortality, injury and behavioural effects associated with vessels**	Site characterisation/ construction/ operation/ decommissioning	Marine mammal collision with vessels is a known risk – most reports involve large whales, but all species can be affected.[288] Marine mammals in the wind farm area are potentially at risk of vessel strike during the site characterisation phase, and throughout wind farm construction, maintenance and decommissioning, leading to injury or mortality. They may also be subject to behavioural and harassment impacts associated with vessel activity during these phases.[289] Any marine mammal using the area is potentially at risk. A study using encounter rate theory has shown that for whales, the overall expected relative mortality is approximately 30% lower where vessel speed is regulated.[290] Turtle species are also vulnerable to vessel strike when they surface to breath, bask or forage at/near the surface.[291] Adult turtles appear to be at increased risk during breeding and nesting season.[292]

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

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

281 Dorsch et al. (2016).

282 Peschko et al. (2020).

283 Humphreys et al. (2015).

284 Drewitt & Langston (2006).

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

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

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

288 Cates et al. (2017).

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

290 Martin et al. (2016).

291 NOAA Fisheries (2017).

292 Ibid.

9	**Mortality, injury and behavioural effects associated with underwater noise**	Site characterisation/ construction/ decommissioning	Marine mammals,[293] turtles[294] and fish[295] are potentially at risk of sub-lethal exposure to underwater noise arising from offshore wind farm site characterisation (impulsive noise from seismic survey air-guns), construction (impulsive noise from piling operations), operation (continuous noise associated with operational wind turbines) and vessel activity (continuous noise from engines and propellers)[296,297, 298] and from decommissioning activities (cutting and drilling to remove/cut off subsea structures). As sound propagates through seawater it loses energy, which happens more quickly at high frequencies but can still be detected tens of kilometres away.[299] Four zones of noise influence are recognised:[300] i) zone of audibility (where animals can detect sound); ii) zone of responsiveness (where animals react behaviourally or physiologically); iii) zone of masking (where noise is strong enough to interfere with detection of other sounds for communication or echolocation); and iv) zone of hearing loss (near enough to the source that received sound level can cause tissue damage or hearing loss). The available data show that all marine mammals have a fundamentally mammalian ear (resembling land mammal inner ears), which has adapted in the marine environment to develop broader hearing ranges.[301] Impacts are best studied for harbour porpoise (*Phocoena phocoena*) and harbour seal (*Phoca vitulina*), grey seal (*Halichoerus grypus*) and bottlenose dolphin (*Tursiops truncatus*).[302,303] These are the more abundant species of shallow shelf seas in Europe, where there is a concentration of offshore wind farm activity. A number of studies have shown disturbance and partial displacement of harbour porpoises up to distances of 20 km during piling activities, reversible within 1–3 days.[304] Hearing capabilities in fish vary substantially between species. One method to understand their sensitivity is based on differences in their anatomy.[305] Some are highly sensitive such as Clupeids (herrings)[306] and Gadoids (cods).[307] Most other species detect sound through particle motion.[308] The current understanding of the impact of anthropogenic underwater sounds on fish is limited by large gaps in knowledge of effects of sound on fishes.[309] However, there is evidence that especially intense sounds affect sound detection and behaviour, and potentially result in injury and death.[310] Whilst there is significant data on hearing in pinnipeds, cetaceans and fish, far less in known about possible impacts on hearing in turtles.[311]

293 Bailey et al (2010).
294 Dow Piniak et al. (2012).
295 Sparling et al. (2017); Thomsen et al. (2006).
296 Hastie et al. (2019).
297 Popper & Hawkins (2019).
298 Weilgart (2018).
299 Nehls et al. (2019).
300 Ibid.
301 NRC (2003).
302 Hastie et al. (2015).
303 Bailey et al. (2010); Nehls et al. (2019).
304 Nehls et al. (2019).
305 Popper et al. (2014).
306 Popper (2000).
307 Hawkins & Popper (2017).
308 Ibid.
309 Hawkins et al. (2015).
310 Hawkins & Popper (2018).
311 Ketten (2017).

10	**Electromagnetic fields of subsea power cables: behavioural effects**	Operation	Studies suggest fish and other benthic organisms could be influenced behaviourally and physiologically by electromagnetic fields (EMF) associated with wind farm cables. These effects depend on type of cable, power, type of current and burial depth. To date, this potential impact is relatively understudied.[312] Electromagnetic-sensitive species come from across many taxa, but there is a paucity of knowledge on a restricted number of species, on how they respond to anthropogenic electric or magnetic fields compared with natural bioelectric/geomagnetic fields.[313] Sensitive species include those with a significant migratory phase, including salmonids and eels, for which EMF may constitute a potential barrier to movement[314] and those with electroreceptors such as sharks, rays, sturgeons and lampreys.[315]
11	**Pollution (dust, light, solid/liquid waste)**	Site characterisation/ construction/ operation/ decommissioning	The site characterisation phase may involve light pollution effects associated with survey vessels (as well as noise, as already noted). Construction, operation and decommissioning can lead to water, dust, waste and light pollution impacts. Examples specific to wind developments are limited, but studies suggest birds and bats may be attracted to lighting at offshore installations.[316,317] Attraction to lighting combined with poor weather conditions (poor visibility) can lead to birds flying at lower altitudes, which can dramatically increase collision risk with anthropogenic structures.[318]
12	**Indirect impacts**	Construction/ operation/ decommissioning	There is potential for the displacement of fishing activities and other marine traffic (shipping routes and recreational vessels), arising from offshore wind farm presence, leading to pressures on biodiversity and ecosystem services (see row no. 13) outside the wind farm area. This can increase pressure on sensitive areas elsewhere, as is reported for Taiwan.[319] Displacement of fishing effort, combined with the habitat created within the wind farm area (see row no. 4), can result in a 'refuge' effect, where fish and benthic communities proliferate in the wind farm area, in the absence of/reduction in fishing activity, with subsequent attraction of predator/foraging species. In areas of weaker governance, such as emerging markets and less developed areas, offshore wind farm construction may also give rise to in-migration of the associated workforce and their families, with induced access to coastal areas via new/improved roads: new human settlements in previously remote areas resulting in degradation of natural habitats; unsustainable natural resource use; and illegal or unsustainable hunting, fishing or harvest of vulnerable species. For onshore facilities, indirect impacts could result from road construction and improvement associated with substations, grid connection, access to the coastal cable landfall site, and any expansion/ enhancement/increased use of ports and harbours. These can increase settlement and induce access to formerly remote areas.

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

313 Perrow (2019).

314 Gill & Wilhelmsson (2019).

315 Ibid.

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

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

318 Hüppop et al. (2019).

319 Zhang et al. (2017).

13	**Associated ecosystem service impacts**	Construction/ operation/ decommissioning	In the offshore environment, construction of a wind farm could lead to loss of important fishing areas and displacement of fishing effort. Some fishing activities may be displaced due to safety or gear limitations (e.g. dredging displaced because of the wind farm structures), but some may continue (e.g. pot fisheries).[320] A study in the German exclusive economic zone (EEZ) of the North Sea indicated that the international gillnet fishery could lose up to 50% in landings when offshore wind farm areas are closed entirely for fisheries.[321] In Korea, a study into the possibility of fishing in an offshore wind farm area, based on the risk associated with the presence of turbines and cables, found the highest risk methods to be stow net, anchovy drag net, otter trawl, Danish seine and bottom pair trawl. Lowest risk methods were single-line fishing, jigging and anchovy lift net.[322] The exclusion of fisheries from the offshore wind farm area may or may not be regulatory – depending on the jurisdiction. In the decommissioning stage, not all structures will necessarily be completely removed – some may be left in place if they have become heavily colonised and support an important ecosystem – thus some fishing activity may still not be possible after the end of the wind farm life for safety reasons. In the nearshore and coastal areas, and in the vicinity of the onshore infrastructure required (substation/grid connection, ports, harbours), there could also be a loss of cultural values, or sense of place/belonging arising from wind farm construction/presence. In some areas, particularly coastal, there might also be tourism, aesthetic-related impacts. These associated ecosystem service impacts could have adverse effects on the well-being of local people. However, it is not yet well understood in relation to offshore wind farm development.
14	**Introduction of invasive alien species**	Site characterisation/ construction/ operation/ decommissioning	Movement of equipment, people or components may facilitate the introduction of invasive alien species (IAS), for example via movement of vessels on hulls and in ballast water and other equipment.[323] The hard substrate used for foundations may provide habitat for invasive species, allowing newly introduced species to become established in the area, or existing populations of invasive species to expand.[324]

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

6.2.2. Biodiversity most at risk

Birds

Seabirds are the primary group of birds at risk of key impacts associated with offshore wind farms – collision and displacement. A review[325] of the existing evidence of seabird collision and avoidance at offshore wind farms (and at onshore/coastal wind farms) found that few studies have been undertaken at constructed offshore wind farms. Most estimates of seabird collision are based on theory rather than empirical evidence, because of the difficulties of monitoring and carcass collection offshore. Gull species are the most regularly reported to collide (followed by terms and coastal and onshore sites) on both onshore and offshore. Avoidance rates for seabirds (calculated from land-based data) also appear higher than previously anticipated, at around 99% or above. Currently, the best available evidence on collision and avoidance comes from a study of Thanet offshore wind farm, UK,[326] where gulls were the most regular fatalities, the main predictor being time spent in flight at rotor height.

The displacement of seabirds from operational wind farms is species-specific, with divers and Northern gannet the most sensitive (based on reviewed studies), and has implications for individual fitness.[327] A review of the displacement

320 Dannheim et al. (2019).
321 Stelzenmüller et al. (2016).
322 Jung et al. (2019); Tonk & Rozemeijer (2019).
323 Geburzi & McCarthy (2018); Iacarella et al. (2019).
324 De Mesel et al. (2015); Perrow (2019).
325 King (2019).
326 Skov et al. (2018).
327 Perrow (2019).

effects of offshore wind farms found that:[328] i) divers, Northern gannet, common guillemot and razorbill show relatively consistent avoidance of areas occupied by turbines; ii) great cormorant and great black-backed gulls appear to be attracted to turbines; iii) the response of some species, mainly gulls, was found to be inconsistent (ranging from strong avoidance to strong attraction); and iv) the overall variation in observed displacement levels is hypothesised to be due to multiple factors, including habitat quality, prey distribution, wind farm location relative to the colony/feeding grounds and wind farm configuration.

Studies and empirical evidence tend to be focused on Europe and UK waters, since this is where the majority of wind farm development has taken place.

Migratory shorebirds and waterfowl

Some shorebirds (order *Charadriiformes*) and waterfowl (order *Anseriformes*) make migratory flights across the open sea and are frequently recorded during monitoring at offshore platforms. However, there is little information on the behaviour of most species during migration or on encountering wind farms. Flight height varies considerably but is frequently <200 m above sea level.[329] Limited research suggests strong avoidance of moving wind turbines by both shorebirds and waterfowl.[330] In the East Asia-Australasia flyway, smaller shorebirds appear to stay mainly close to shore, or to make short flights across open sea.[331] By contrast, some larger shorebird species are known to make very long ocean crossings.[332]

Based on observations at onshore wind farms and modelling, some shorebirds and a few waterfowl are considered at relatively high risk of collision. Migratory shorebird species are increasingly threatened by loss of critical staging grounds,[333] among other factors, with some species at high risk of extinction. Wind power has been highlighted as a potential threat to shorebird migrants, particularly near to shore, in the Yellow Sea[334] – a major stopover site on the East Asia-Australasia flyway.

Migratory landbirds. The risk associated with offshore wind farms is generally lower for landbirds, primarily because they are less likely to encounter the turbines. Few resident passerines are active offshore, and most individuals will only rarely encounter turbines. However, nocturnal migrant passerines are at risk of collision because they can be drawn to the nacelle lights.[335] Onshore, the bulk of individuals migrate above the height of current rotor blades[336] and on a broad front,[337] meaning few individuals would encounter each turbine. This may not be the case over the sea. Landbirds tend to use well-known routes to cross open water, typically trying to minimise time spent over the sea. This is especially marked for soaring birds, such as raptors or storks, which cannot easily use soaring flight over water, but smaller passerines and near-passerine species will also move along coastlines to locate favourable crossing places.[338] This means that many individuals concentrate at 'bottleneck' crossing routes such as the Strait of Gibraltar and Bab-el-Mandeb on the Arabian Peninsula.[339] These locations should be avoided for offshore wind farms.

For the onshore component of offshore wind developments, species with high wing loading (weight to wing area ratio), such as bustards, cranes, storks, geese and swans, eagles and vultures, are at higher risk of collision with transmission lines associated

328 Rydell & Wickman (2015).
329 Hüppop et al. (2019).
330 Ibid.
331 Choi et al. (2016).
332 Alves et al. (2016); Conklin et al. (2017).
333 MacKinnon et al. (2012); Szabo et al. (2016).
334 Melville et al. (2016).
335 BirdLife International (2009).
336 For example, Dokter et al. (2011; 2013).
337 For example, Aurbach et al. (2020).
338 Aurbach et al. (2020).
339 Bensusan et al. (2007); Meyburg et al. (2003).

with grid facilities due to low manoeuvrability. Flocking, migration and nocturnal activity are all associated with high collision levels in some species, but are not consistently high-risk factors.[340]

Bats

Compared to birds, there is limited information on the potential for bat collisions with offshore wind turbines. A 2017 study of the global vulnerability of bird and bat species to collision mortality and wind farms found that no collision rate data were available for offshore wind farms (and that the available data were largely from well-studied parts of Europe and North America).[341] However, bat species are known to seasonally occur offshore. Eleven species of bats have been recorded flying and feeding over the sea up to 14 km from the shore,[342] and historical records indicate individual bats have ranged hundreds of kilometres from shore.[343]

There is little information on flight altitudes of different species during straight migration flights, and there is uncertainty regarding the likely behaviour of bats passing an operational wind farm.[344] Relationships between bat activity and weather parameters may differ between species, sites and years.

The German BATMOVE project aims to improve knowledge about the spatial and temporal distribution, and connectivity, of migrating bats over the North and Baltic Seas using acoustic detection. BATMOVE pilot surveys at the FINO 1 research platform in the North Sea, in the vicinity of three operational offshore wind farms (Alpha Ventus, Borkum Riffgrun I and Trianel Windpark Borkum), confirmed bat (*Pipistrellus* and *Nyctalus* species) activity in the area.[345] A long-term acoustic bat survey at remote islands, offshore structures and coastal sites in the Gulf of Maine, Great Lakes and mid-Atlantic coast[346] found that offshore bat activity: i) was highest near heavily forested coastal areas or islands; ii) generally increased rapidly during the first hour after sunset, then declined steadily for the rest of the night; iii) lessened as distance from the mainland increased (this effect was reduced where there were lots of islands); and iv) correlated closely with season, increasing during warmer periods and lower wind speeds, and peaking from 15 July to 15 October, when most bat activity also occurred on land. The most frequently detected species group in the study was *Myotis* genus. At offshore structures, specifically, the Eastern red bat (*Lasiurus borealis)* was the most commonly identified. The Eastern red bat is a tree bat that undertakes long-distance migrations in the autumn, using the same migratory routes along the Atlantic seaboard as many birds.[347] Behavioural information such as this is invaluable for developing mitigation measures appropriate for bat species.

Marine mammals

Marine mammals naturally occur in probably every offshore wind farm worldwide,[348] where they are exposed to noise impacts during construction, operation and decommissioning, and risk collision with vessels and changes in available habitats and hydrodynamics (Table 6-1). However, they may also benefit from refuge effects created in wind farm areas. Underwater noise impacts are best studied for species common in the area of European offshore wind farms, such as the harbour porpoise (*Phocoena phocoena*) and harbour seal (*Phoca vitulina*), grey seal (*Halichoerus grypus*) and bottlenose dolphin (*Tursiops truncatus*).[349] The sensitivity of seals to underwater noise impacts is

340 Bernardino et al. (2018).
341 Thaxter et al. (2017).
342 Ahlén et al. (2009).
343 Pelletier et al. (2013).
344 Ahlén et al. (2007).
345 Bach et al. (2017).
346 Peterson et al. (2016).
347 Bat Conservation International (2019).
348 Nehls et al. (2019).
349 Gordon et al. (2019); Hastie et al. (2015); Nehls et al. (2019); Schaffeld et al. (2020).

considered to be much lower than cetaceans.[350] While hearing capabilities vary between species, it is not unreasonable to assume that any cetacean or pinniped species in the vicinity of offshore wind farm construction noise could be at risk. With respect to vessel activity strike, cetaceans and pinnipeds are at risk when they are at or near the surface.

Turtles

With respect to offshore wind farms, risk to turtle species is less well-studied than for marine mammals, birds and fish, but this is likely because of the geographic locations in which offshore wind farm development has proliferated to date. Turtles may be at risk associated with EMF emitted from offshore wind submarine cables, or may be attracted to the habitat created through the introduction of new hard substrate on towers, foundations and sour protection (Table 6-1).[351] They may also be impacted by underwater noise.[352]

Fish

As construction of offshore wind farms can degrade benthic habitats and produce high levels of underwater noise, benthic fish species and those that are considered hearing specialists, such as clupeids (herrings)[353] and gadoids (cod),[354] may be more at risk due to the development of offshore wind farms. Fish species with electroreceptors (sharks, rays, sturgeons and lampreys),[355] and those a significant migratory phase (salmonids and eels)[356] may be at risk from EMF emitted from offshore wind submarine cables, which may constitute a potential barrier to movement or influence behaviour. However, there remain gaps in the knowledge of the effects of sound on fish.[357]

Habitats

Offshore wind farms could impact a variety of offshore and coastal habitat types, such as sandbanks, coral reefs, seagrasses, mangroves, salt marshes, oyster beds and wetlands. These habitats may also provide important ecosystem services such as fisheries and coastal protection. Such habitat types are sensitive to loss, fragmentation and degradation, and restoration can be complex and variable by life stage.[358] Careful planning and site selection are key to avoiding sensitive habitats (Section 3), for example to minimise impacts of the export cable landfall.

6.2.3. Population level and cumulative impacts

As offshore wind farm development gathers pace, the potential cumulative impacts of offshore wind farms are increasingly important, yet can be difficult to investigate. This can be improved through the development of cumulative impact assessment frameworks,[359] regional coordinated survey and monitoring efforts and data transparency (Section 8).

Individual wind farms are rarely likely to cause effects at the population scale[360] of birds. Issues include cumulative barrier impacts of multiple wind farms on a particular migratory flight path, cumulative habitat loss from displacement or behavioural interference, and the cumulative underwater noise impacts and increased potential for vessel strikes due to the installation/construction of multiple projects (Annex 2, case study 23). The

350 Nehls et al. (2019).
351 Tethys (2020).
352 Inger et al. (2009); Samuel et al. (2005).
353 Popper (2000).
354 Hawkins & Popper (2017).
355 Gill & Wilhelmsson (2019).
356 Ibid.
357 Hawkins et al. (2015).
358 Basconi et al. (2020).
359 van Oostveen et al. (2018).
360 King (2019).

complexity of the latter is further compounded by the need to consider the spectrum of scenarios from concurrent to sequential construction, the variety of foundation installation techniques and the seasonality of marine fauna movements/behaviour.[361] Furthermore, if developments are not carefully sited and coordinated, they have the potential to impact KBAs due to a relatively large geographic footprint (Section 3).

6.3 Project design phase mitigation

6.3.1. Overview

The project design phase typically begins once a site is identified and a decision made to invest in its development. Risk screening and/or review of existing strategic assessments (Section 3) are essential steps before the project design phase to avoid developments taking place in sensitive sites. Engineering design will consider wind farm size, turbine type, hub height, layout, electrical design and connection to shore to maximise energy production and minimise capital and operating costs. It will also need to account for the outcome of site characterisation including constraints imposed by wind resource, seabed topography, environmental and social considerations (including potential cumulative impacts), geotechnical considerations, grid connection and other sea users), as well as local regulations[362] and seabed policy or zoning, geopolitical risks, accessibility and financial incentives.

The identification of *avoidance* and *minimisation* measures to prevent and reduce adverse biodiversity and ecosystem service impacts are a primary consideration throughout the planning and design phase of an offshore wind project. A robust biodiversity baseline early in the project design phase is essential for assessing the risk of an impact occurring (Section 8.1), and identifying appropriate avoidance and minimisation measures. The most effective measures are often those that are planned into design early, when changes in infrastructure siting and operational planning are still feasible. The process is iterative.

Avoidance and minimisation measures should be applied and reviewed repeatedly until impacts are either eliminated, or reduced to a level where no net loss or net gain of biodiversity can feasibly be achieved through restoration and/or offsetting. The iteration is important because restoration and offset measures can be costly, and there is a time lag in their realisation (Section 2). Optimising avoidance and minimisation measures early on reduces (or potentially removes) the need for expensive restoration and offsetting later. Hence, it is important to maintain close engagement throughout the design phase with project engineers, such that planned avoidance and minimisation measures are practical and implementable.

6.3.2. Avoidance and minimisation during site characterisation

After an offshore wind farm site has been identified, and before detailed project design work can be done, work to characterise the geological and environmental conditions of the site is necessary. First, geophysical surveys are carried out across the wind farm site and the cable route (usually comprising seismic methods, echo sounding and magnetometry) to map the seafloor, understand bathymetry and identify obstacles (marine archaeological features or unexploded ordnance), and to produce charts and maps for GIS and site layout design.[363] This work informs the geotechnical and benthic surveys that follow, which can include seabed core and grab sampling to ground-truth the geophysical surveys, and profile physical and chemical soil characteristics and benthic fauna.

361 Goodale et al. (2019); Leopold et al. (2014); Masden et al. (2009), (2015).
362 Nehls et al. (2019).
363 BVG Associates (2019).

While most of this site characterisation work is non-intrusive (swathe bathymetry) and/or spatially discrete (non-intrusive point benthic sampling, informed by geophysical data) with limited potential to impact biodiversity, seismic surveys could pose a risk to marine mammals.[364] Since it is necessary to penetrate only a few metres into the seabed, the risks of low-energy systems such as pingers and chirpers) to marine mammals are considered low.[365]

However, impulsive sources of underwater noise are among the most intense sounds in the ocean and can cause a range of impacts on marine fauna. Noise from detonation of unexploded ordnance and seismic airguns (and pile driving; Section 6.4.3 and Box 11) can travel great distances.[366] It is thus important not only to consider the least-impactful equipment necessary to collect the required geophysical data, but also to plan site characterisation work to **avoid disturbing species during sensitive periods of their lifecycle** (also Section 6.4.2 – avoidance through scheduling in the construction phase). If it is necessary to detonate unexploded ordnance located in the planned wind farm area, **noise mitigation measures (Box 11) should be implemented to minimise impacts** on marine mammals and other fauna.

The site characterisation phase also requires increased/concentrated vessel activity in the planned wind farm site. Therefore, avoidance and minimisation measures should be implemented to manage risks to biodiversity associated with vessels (Section 6.4.3).

6.3.3. Avoidance and minimisation through project design

After site selection, there are opportunities for mitigating biodiversity impacts through design decisions.[367] Avoiding and minimising impacts through project design for offshore wind developments often involves three main measures implemented within an offshore wind farm site and its power evacuation route:

- **Changes to the layout of project infrastructure** (termed 'micro-siting');
- **Selecting or designing** project components to avoid or reduce biodiversity impact; and
- **Re-routing, marking or burying onshore powerlines**.

Effective implementation of these measures requires a comprehensive biodiversity baseline, including identification of particularly sensitive areas on the project site, a good understanding of the behaviour of at-risk species and the ecosystem service-dependencies and values that people place on nature at the site.

Micro-siting measures

Detailed and specific decisions regarding the location of individual pieces of project infrastructure are often termed '**micro-siting**'. Avoidance through micro-siting typically focuses on placing development, or components of development, away from sensitive biodiversity areas and altering wind farm layouts to minimise barriers to movement.

Sensitive areas can be avoided through careful siting of:

- Offshore foundations/turbines;
- The export cable and the cable landfall location; and
- Onshore access roads, etc.

The aim is to avoid direct loss or degradation of sensitive habitat, reduce habitat fragmentation and barrier effects, and decrease mortality risk of associated species. Some important areas for biodiversity are more sensitive at particular times of the year (e.g. during species' breeding seasons), and some may be sensitive due to a particular activity associated with offshore wind farm development/operation such as foundation installation noise impacts on marine mammals. Micro-siting to avoid sensitive habitats

364 For example, a mass stranding event of melon-headed whales in Madagascar has been linked to the use of a multibeam echo sounder system 65 km offshore (Southall et al., 2013).

365 Nehls et al. (2019).

366 Merchant et al. (2020).

367 In UK offshore wind project impact assessments, designed-in mitigation measures are often referred to as 'embedded' mitigation, with measures identified/implemented after the project design phase often called 'additional' mitigation measures. The terminology has no practical or material implications for the design or implementation of the mitigation measures themselves, and the distinction has not been made in these guidelines.

through project design will usually be informed by earlier-stage risk screening (Section 3.4), site characterisation work and baseline surveys carried out to support ESIA. Section 8 for information on implementation of surveys for impact assessment, monitoring and evaluation.

Mitigation of temporal impacts can be addressed through operational, physical and abatement controls, and is addressed in Sections 6.4 and 6.5.

Particularly sensitive areas to avoid during project design include:

- **Marine Protected Areas** and other relevant types of exclusion zones or controlled areas**, Important Marine Mammal Areas (IMMAs), Key Biodiversity Areas (KBAs), Ecologically or Biologically Sensitive Areas (EBSAs), Particularly Sensitive Sea Areas (PSSA)**;
- Areas that are known to support **threatened ecosystems or species** (e.g. offshore foraging areas, breeding grounds and areas on migration routes);
- Areas along **migratory corridors** that support high concentrations of birds (including the main migratory route and coastal staging areas/stopover sites and coastal 'bottleneck' areas such as narrow straits), marine mammals and fish;
- Important **nesting, roosting, foraging** and **overwintering areas** for birds and bats in coastal areas where the offshore wind farm cable makes landfall, or offshore areas of seasonally important foraging habitat;
- **Features that concentrate species' movements**, such as sandbanks (coastal and offshore – birds and marine mammals), coastal wetlands and marshes and coastal areas of high relief such as ridges and cliff edges (birds) and heavily forested coastal areas (bats); and
- Other features and important sites that people value or depend on for delivery of ecosystem services such as important fishing grounds and natural sites of aesthetic value or cultural significance.

Micro-siting measures for offshore wind farms to date have mainly focused on reducing bird and bat collisions. A prime example of this is the re-siting of specific 'problem' turbines to reduce the risk of collision mortality. However, although sensitivity mapping might provide useful information, in practice it is difficult to identify such turbines at the design stage, and it is unlikely that once installed, it will be practical to re-site an offshore wind turbine. Therefore, the most effective means of reducing the potential for collision is to avoid migration routes and important foraging areas (Section 6).

More broadly, the **configuration of turbines** in the wind farm area can be designed to help reduce barriers to bird movement and minimise risk of collision. When there is a clear direction to migration or other movements (e.g. between roosting/nesting and feeding areas), movement corridors can be created by aligning widely-spaced turbine clusters that run parallel to, rather than across, the predominant flight direction.

Such measures could reduce the risk of collision for birds travelling between roosting, feeding or nesting sites. While these measures are recommended in the existing literature, they have been based on inferences made of bird avoidance behaviour at wind farms, and further studies are needed to confirm their effectiveness.[368]

There may be other considerations also affecting turbine layout, such as visual/seascape assessment, allowing safe vessel passage, or potential disruption to local fisheries activities. The challenge of aligning all these considerations emphasises the importance of optimised site selection (Section 3). In locations with well-developed policy, regulation and enforcement systems such as in Europe and the USA, such considerations are likely to be easier to identify and address than in less-developed regions where there may be multiple overlapping rights (real or perceived) and where regulation/enforcement is poor/non-existent).

Establishing appropriate avoidance zones around sensitive areas for biodiversity can be implemented with the intention of minimising collision risk and disturbance to at-risk species. For example, it may be appropriate to consider the proximity of nearshore

368 Drewitt & Langston (2006); Langston et al. (2004).

wind farms to adjacent coastal features which may provide habitat for birds or bats that would use the offshore wind farm area.[369] Expert input can help to identify such areas, and to determine avoidance distances specific to the circumstances on site.

Micro-siting is also important with respect to the **export cable**, which may need to traverse a significant distance from the offshore substation to the point of landfall. The route should be selected to avoid sensitive benthic zones, such as reefs, wetlands and other important coastal ecosystems, and the installation method should be selected to reduce impacts such as sediment plumes. The method of export cable installation at the landfall site should also be selected to avoid impacting sensitive areas (Annex 2, case study 2). Depending on geology and topography, horizontal directional drilling (HDD) can be a relatively low impact method of installing the export cable at landfall, since it avoids the need for a cable trench, and can mean that the cable exits in the subtidal rather than the intertidal zone.

In all drilling activities, it is also important to consider the drilling mud/fluids such that they are non-toxic, inert and aligned with any national/regional registers of chemicals permitted for use in the marine environment.[370] Box 12 provides more information on minimising the disturbance associated with cabling.

As well as drilling fluids, antifouling and anticorrosion treatments/paints and operational liquids and lubricants should also be selected to avoid and minimise potential impact.

Design of project components

Some project components can be **selected or designed** to avoid or reduce biodiversity impact. For example, the size/power rating of offshore wind turbines has implications for the **project layout/configuration**. Simplistically, a wind farm can be configured with a smaller number of larger turbines, or a larger number of smaller turbines (and theoretically, anything in between). There are multiple trade-offs to consider in terms of biodiversity impact. Larger turbines have a corresponding larger rotor swept area, which is important with respect to collision risk. However, overall, the rotor swept area may be reduced, or condensed, compared to a project with smaller turbines that is laid out over a larger area. Larger turbines are also taller, which may therefore interact with birds with different flight heights than smaller turbines, or with birds during a different period of activity/behaviour. On the other hand, the use of larger turbines may reduce the project balance of plant, meaning fewer offshore structures and reduced array cable requirements.

Another example of selecting or designing components to mitigate impacts is the choice of **foundation type**. Monopile, jacket and tripod foundation types are common, but installation is a noisy process involving piling or hammering, and this noise can affect marine mammals and fish in various ways, depending on proximity and species-specific sensitivity to noise. **Alternative foundation types** should be considered to reduce or avoid the noise impact, such as 'quiet' foundation types (gravity bases or suction buckets/caissons), which are floated out to position and submerged. Gravity base foundations are concrete, filled with water and sand and sunk onto the prepared seabed. Suction buckets are upside down steel buckets sunk directly onto the seabed and pumped to remove the water and air, creating negative pressure inside the bucket that drives the foundation into the seabed.

There are also several methods of minimising (abating) underwater noise, which may also influence design decisions (Section 6.4.3 and Box 11). As always, there will be multiple other considerations to weigh up in such decisions (such as the need for seabed preparation (levelling) for gravity base foundations), but ideally these will have been addressed earlier in site selection or micro-siting, to avoid benthic disturbance in sensitive seabed areas such as reefs or other refuge/nursery areas. Greater cost may also limit the feasibility of alternative foundation types in some cases. Floating wind farms avoid the need for foundations (and the noise associated with installing turbines). The floating wind industry is currently not as commercially well advanced as the

369 See, for example, Woodward et al. (2019) who analysed foraging ranges from UK seabird breeding colonies to inform understanding of potential interactions between these colonies and proposed offshore wind development areas.

370 Such as the Offshore Chemical Notification Scheme operated by Cefas in the UK.

fixed offshore wind industry, and so as yet it may not represent a feasible alternative. A brief summary of floating offshore wind and the associated impacts/ mitigation is given in Box 10.

Related to the foundation type is the need for appropriate **scour protection** at the base of the turbine and along the export cable, to protect the integrity of these components and to prevent the downstream effects of sediment accumulation. It is essential that the potential for seabed scour is understood and that preventative measures are applied, as opposed to remedial measures that can be costly and difficult to apply. Scour protection may include rock dumping (most common) around the turbines and along array/export cables, packed rocks (or 'geotextiles' – sacks or flexible containers filled with heavy material and placed at the base of the turbine to mould around the tower) and specially-designed concrete mattresses placed around the base of the turbine. Less-tested methods include using mats made of rubber or rubber-derivatives such as used rubber from car tyres.

Like the introduction of the turbine towers themselves, scour protection can increase the availability of hard substrate in the wind farm area.[371] This can lead to the development of new benthic communities[372] and alteration of fish distribution and diversity in the locality – referred to as the **artificial reef** effect (Annex 2, case study 17). It is often considered a positive effect, but may raise other issues, such as unauthorised access to the wind farm area to exploit increased fish populations, or the attraction of foraging seabirds (thus increasing potential for collisions). Fish populations may also increase in the wind farm area due to the '**reserve effect**', whereby the presence of the wind farm itself prevents commercial fishing activity in that area, thereby allowing fish populations to increase, or fish to shelter in the wind farm area.

Scour is also an issue related to the export cable, which is likely to require protection at key points to avoid damage (Box 12). Cable protection material should be selected to be similar to the seabed environment, and their installation/alignment should consider the local sand wave field such that secondary scour is reduced/avoided and downstream sediment transport is not affected.[373]

Electromagnetic fields (EMF) emitted by export and array cables can affect sensitive fish, marine mammals and turtles. However, the impact on species is not well understood, and therefore options for mitigation, if required, are also unclear. Burying cables in non-magnetic substratum has been suggested as a means of making the EMF equal to the natural background EMF,[374] but may not be effective.[375] Other measures include using cable sheathing with high conductivity and permeability to help reduce the magnetic field.[376]

Re-routing, marking or burying powerlines

High voltage onshore transmission lines used to evacuate power from the wind farm can pose a collision risk to some bird species. Transmission lines should, as far as possible, be routed to avoid sensitive areas where there may be high traffic of birds at risk such as near wetlands, waste sites[377] and within bird migration corridors. This is a consideration in early planning, but further re-routing may become necessary once more detailed information is available on the presence and movements of at-risk bird species.

Marking transmission lines with bird diverters is now standard good practice, and on average has been shown to halve the numbers of collisions.[378] This may not be sufficient where there are risks to species of high conservation concern. For large bats, electrocution risk can be reduced by orienting wires

371 The installation of a monopile foundation and the associated scour protection can create 2.5 times the amount of area that was lost through installation (Wilson & Elliott, 2009).

372 Raoux et al. (2017).

373 Natural England (2018).

374 Hutchison et al. (2018).

375 Baruah (2016).

376 Tricas & Gill (2011).

377 Haas et al. (2004).

378 Bernardino et al. (2019).

horizontally rather than vertically, as observed in frugivorous bats in Sri Lanka.[379]

Burying transmission lines poses technical challenges and costs, but is an effective way of avoiding impacts where the lines pass through particularly sensitive areas such as near wetlands and within bird migration corridors[380] and needs serious consideration in such cases.

It is recognised that burying of transmission lines could pose risks to biodiversity, particularly during its installation that requires consideration. In certain cases, major earthwork activities could result in the loss of habitat for plants, amphibians and/or reptiles of high conservation concern. It could also disrupt important linear features, such as rivers, and heighten the risk of invasive species ingress along the disturbed cable route. This measure is therefore a suitable alternative provided it is appropriately risk assessed. Where transmission lines run above ground, minimisation measures, such as bird diverters, will usually be needed. In some wind farms, power evacuation may be via medium-voltage lines. If poorly designed, these can pose a significant electrocution risk to many larger birds, especially birds of prey. It is, however, straightforward (and usually adds little if any cost) to construct safe distribution lines, with insulation and spacing of conductors that eliminate electrocution risk for birds. Detailed guidance may be found in Annex 1.

Box 11 Floating offshore wind farms – status, impacts and mitigation

Floating offshore wind is a relatively new market, but development is gathering pace. The International Renewable Energy Agency (IRENA) estimates that by 2030, around 5 GW to 30 GW of floating offshore capacity could be installed worldwide, and that floating wind farms could cover 5–15% of the global offshore wind installed capacity by 2050.[381] The first floating offshore wind project, Hywind Scotland Pilot Park (30 MW), was commissioned in 2017 and at the end of 2018, there were nine floating offshore wind installations – four in Japan and five in Europe, with a cumulative capacity of 50 MW. Thirteen more have been announced globally.[382]

Floating offshore wind allows access to deeper water sites compared to fixed turbines, turbine set-up is easier, and they have a lower impact due to less-invasive seabed installation activity. They may also, in time, offer a lower-cost alternative to fixed foundations.[383]

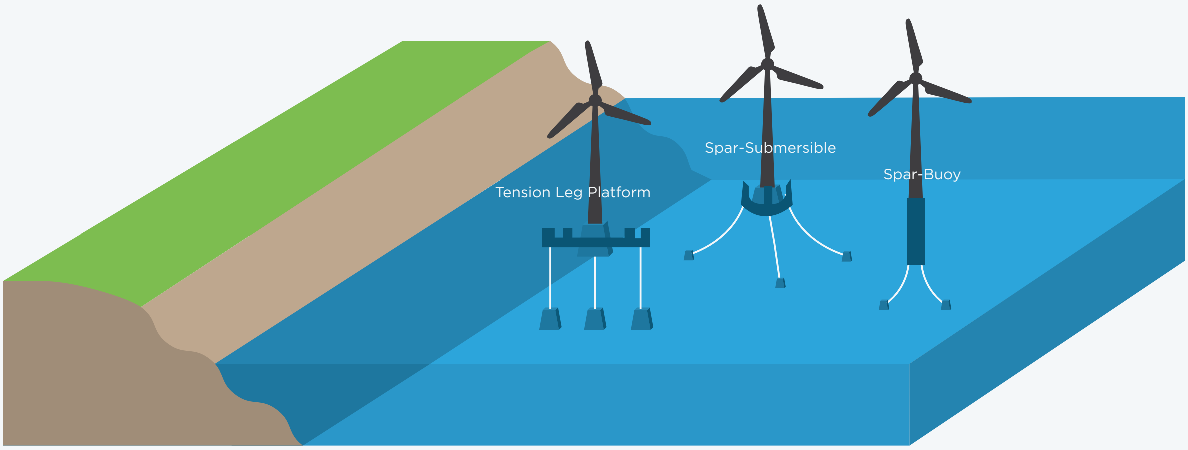
Essentially, a standard wind turbine is mounted on a floating structure. Three main designs are under development and have been tested: spar buoys, spar-submersibles and tension-leg platforms (Figure 6a). Mooring configurations are either taut-leg (for tension-leg platforms), or catenary (used with spar-buoy and semi-submersible) systems.[384] Catenary systems have a larger seabed footprint than taut-leg systems, but they are generally simpler to install.

The anchoring system depends on the mooring configuration, seabed conditions and the holding capacity required. Catenary mooring configurations often use drag-embedded anchors, but piled and gravity anchors are also used. Taut-leg configurations typically use driven piles, suction piles or gravity anchors. The size of the anchor is also variable.[385] There is a noise impact associated with the driven pile. The suction pile is least invasive. There are small-scale seabed impacts associated with drag anchors.

379 Tella et al. (2020).
380 Bernardino et al. (2018).
381 IRENA (2019b).
382 Ibid.
383 IRENA (2016).
384 Carbon Trust (2015).
385 Carbon Trust (2015).

The array cables are dynamic – they need to be designed to move in the water column – so buoyancy elements are included, as is a small anchor where the cable meets the seabed. Array cables lie on the seabed, or are buried. The export cable is buried in much the same way as for fixed installations, and may also require protection in some locations.

Figure 6a Floating offshore wind mooring concepts



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There are concerns regarding the potential for large whales to collide or entangle with the lines and cables associated with this type of installation, with risk of injury or death, but to date there are few floating arrays where this can be studied and modelling approaches have been tested.[386] A report into these risks concluded that marine renewable energy devices would 'likely pose a relatively modest risk in terms of entanglement for most marine megafauna, particularly when compared to the risk posed by fisheries', but that there was a potential risk in particular for large baleen whales, and if 'derelict fishing gears become attached to the mooring, thereby posing an entanglement risk for a wide range of species, including fish and diving seabirds'.[387]

6.4 Mitigation in the construction phase

6.4.1. Overview

The project construction phase involves preparation of equipment and components, mobilisation of contractors, onshore land and offshore seabed preparation works, civil engineering works (including new or upgraded ports and harbours, and new or widened access tracks/roads to accommodate large component logistics), and electrical works. Broadly, the sequence of offshore wind farm installation is as follows: onshore substation and onshore export cables; foundations; offshore substations; array cables; offshore export cables; and finally, turbines. Onshore grid connection/electrical work typically include upgrades to existing infrastructure or the construction of a new substation to connect to the existing electricity network.

The offshore installation period is variable, considering weather down time and significant wave height, which limits offshore construction activity. The further offshore a site is, the more likely it is to be

386 Copping & Grear (2018).
387 Benjamins et al. (2014).

subject to adverse weather conditions and higher weather downtime,[388] with implications for the extent to which the installation period can be amended for biodiversity impact mitigation purposes.

Key *avoidance* and *minimisation* measures for the construction phase involve consideration of changes to the construction works schedule and implementing physical, operational and abatement controls. Progressive ecological *restoration* of onshore temporary facilities, such as lay-down areas or construction roads, and any Proactive Conservation Actions (PCAs) such as habitat creation or enhancement work (Section 7.2) also need to be planned and implemented throughout construction.

In some cases, opportunities for new mitigation measures, or a more efficient implementation of the mitigation measures, are identified after the project design phase when construction has begun (or during the handover process from design to construction). Thus, minimisation by physical controls at this point involves **modifying the physical design of project infrastructure during construction** to reduce operation-related impacts on biodiversity and ecosystem services. Measures recommended to date mainly focus on **modifications to wind turbines and any onshore overhead transmission lines** to reduce risk of bird collisions. Section 6.5 addresses those measures providing mitigation of impacts during the operational phase.

Sometimes during the construction phase, unforeseen issues can arise that necessitate a change to the project design. This can result in further detrimental impacts to biodiversity and the associated ecosystem services, and could trigger a requirement to update the project ESIA, and/or apply for amended consents. It is vital that any such changes are identified as early as possible, to enable any additional ecological surveys and assessments required to be completed with minimal disruption to the construction programme.

Good practice mitigation measures for the construction phase are generally applicable to all types of developments, including offshore wind, and can help identify appropriate practices to avoid and minimise impacts during project construction.

6.4.2. Avoidance through scheduling

Avoidance through scheduling involves **changing the timing of construction activities** to avoid disturbing species during sensitive periods of their lifecycle. This is the most effective means of construction phase mitigation, and is also an important consideration in avoiding/minimising aggregated and cumulative impacts (Section 3.2).

Construction schedules will need to account for seasonal aggregations (important/essential feeding, breeding, calving and/or migratory periods) and diurnal or nocturnal movement patterns of species of concern. For example, disturbance to migratory seabird species can be completely avoided if construction activities occur outside the migration period. For some activities, such as seabed preparation work or cable laying, birds flying in transit over the site may not be of concern. However, these activities temporarily affect turbidity in the water column, which can in turn impact productivity (depending on how sustained the effect is), and potentially the foraging success of species that forage/hunt by sight.

However, onshore and cable landfall works could result in disturbance to coastal bird species, which could be avoided by not carrying out works in or near to coastal protected or sensitive areas, or minimised by scheduling activities outside of sensitive periods.

Where possible, foundation installation schedules should account for marine mammal breeding and migratory periods and fish spawning activity/migrations, and ideally installation activity should be postponed during these periods. The installation protocol may also need to account for occasional, or even daily, presence of marine mammals in and around the wind farm site (Annex 2, case study 30) (Section 6.4.3).

Information on migratory behaviour is generally best for bird species, although data vary regionally

388 BVG Associates (2019).

and with species for birds, bats, marine mammals, marine turtles and fish. As with project design, effective avoidance through scheduling requires a good understanding of the seasonal and diurnal activity patterns of sensitive species, to be able to identify key periods to avoid. These may be linked to seasonality in the ecosystem, such as diurnal/nocturnal prey availability,[389,390] or the presence of temporary wetlands. There may also be project and logistical constraints on scheduling, as well as issues of weather and sea state conditions offshore. Close collaboration between project planners, engineers and environmental specialists is required to ensure mitigation through project scheduling is effective.

6.4.3. Minimisation

Minimisation in the construction phase can be categorised as:

- Minimisation by **abatement controls,** involving taking action to reduce emissions and pollutants (dust, light, noise and vibration, solid/liquid waste) that could negatively impact biodiversity and ecosystem services;
- Minimisation by **operational controls,** involving managing and regulating contractor activity and movement.

There are two broad approaches:

- **Selecting construction methods** to minimise impacts, for example, related to:
  - Underwater noise, including implementing noise reduction methods during construction (Box 11); and
  - Cable installation, by jet ploughing where appropriate, to reduce benthic disturbance (Section 6.4.3).

- **Implementing construction protocols** to minimise potential for impact (Annex 2, case study 30). For example:
  - Managing vessel movements/activities;
  - Other impacts, including ensuring proper disposal of solid and liquid wastes and implementing a protocol for rapid management of any chemical leaks or spills;
  - Enforcing good behaviour by construction workers, including prohibition of hunting, trapping, fishing, and general harassment of wild animals; and
  - Applying good practice mitigation measures for waste management related to, for example, construction ports/harbours and any staff or contractor housing (see general guidance applicable to all types of developments).

Abatement controls

Underwater noise

One of the most important biodiversity impacts of offshore wind farm construction is associated with **underwater noise**. Ideally, development should be avoided in areas of known marine mammal sensitivity (Section 3). Where development proceeds and piling and hammering to install foundations cannot be avoided (e.g. by selecting an alternative foundation type) (Section 6.3.3), careful management of the process and monitoring of the surrounding sea area can reduce the level and duration of underwater noise that species are exposed to. Box 12 summarises approaches to minimising the adverse impacts of underwater noise associated with foundation installation. Vessel noise is also a consideration, mitigated through selection of the appropriate vessel types and controls on vessel activity.

Minimising underwater noise impacts on marine mammals and fish is dependent on an understanding of species-specific hearing capabilities and the physiological effects of underwater noise beyond ambient levels. Some species are much better studied, such as the grey seal *(Halichoerus grypus)*[391] and harbour seal (*Phoca vitulina*),[392] harbour porpoise (*Phocoena phocoena*),[393] dab (*Limanda*

389 Shealer (2001).
390 Brooke & Prince (1991).
391 Aarts et al. (2017).
392 Finneran (2015); Hastie et al. (2015); Kastak et al. (2005).
393 Brandt et al. (2018); Finneran (2015).

limanda),[394] Atlantic salmon (*Salmo salar*)[395] and Atlantic cod (*Gadus morhua*),[396] than others (e.g. baleen whales). Defining an appropriate mitigation zone requires information on the different zones of noise influence for a given species (see Table 6-1), as influenced by site-specific conditions such as seabed type and water depth. Data are variable and more research is certainly required. In the absence of species-specific information, it may be appropriate to use better-studied 'proxy' species to inform mitigation protocols, and best-practice protocols should be implemented.

Box 12 Minimising adverse impacts of underwater noise on fauna

Marine mammals, fish and turtles are at risk of impacts associated with underwater noise during wind farm construction (Table 6-1). This box summarises abatement controls and approaches to minimise this risk.

Piling protocol

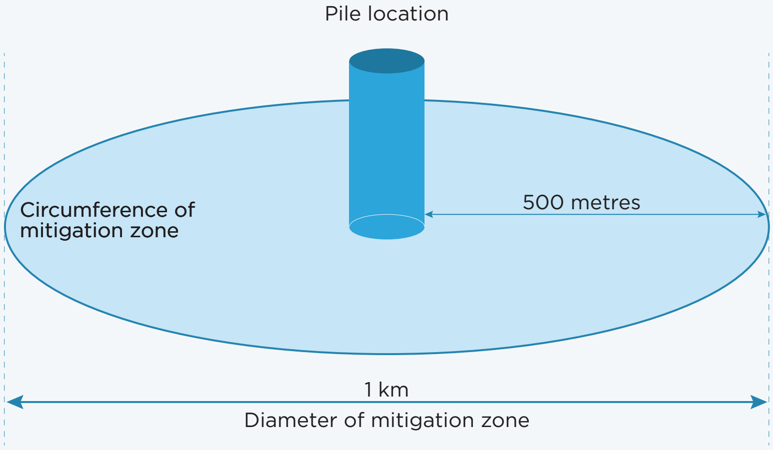
Best practice for mitigation of piling impacts on marine mammals has been developed by Natural England, the Countryside Council for Wales and the Joint Nature Conservation Committee (JNCC), UK's statutory nature conservation bodies. The 'piling protocol' is also considered appropriate for mitigation of impacts on marine turtles and basking sharks, and has been designed to 'reduce to negligible levels the potential risk of injury or death to marine mammals in close proximity to piling operations'.[397] Similar guidelines and protocols from other countries are often based on the JNCC protocol. Multiple examples of its use and adaptation can be found in the environmental documentation for offshore wind farms, generally made available online through individual project websites and the relevant government agency responsible for consenting (e.g. the UK's National Infrastructure Planning portal or the U.S. Bureau of Ocean Energy Management).

The piling protocol is suitable for use in any region, and can be easily adapted. It addresses the following considerations: the role, training and equipment requirements of the marine mammal observer (MMO); the mitigation zone; the pre-piling search; delay if marine mammals are detected in the mitigation zone; soft-start piling procedures; breaks in piling activity; acoustic deterrent devices (ADDs); and reporting protocols.

The **mitigation zone** is a minimum radius of 500 m from the piling location, and is the area monitored by the MMO and passive acoustic monitoring (PAM) or near real-time PAM[398] operative prior to piling (Figure 6b). The extent of the mitigation zone can be variable depending on the species of potential concern, as agreed with the relevant authority and as advised by specialists. If mammals are detected in this zone during the pre-piling search, the protocol recommends that commencement of piling is delayed (Annex 2, case study 20).

394 Thomsen et al. (2008).
395 Harding et al. (2016).
396 Thomsen et al. (2008; 2012).
397 JNCC (2010).
398 See the Melville Buoy (n.d.).

Figure 6b. Representation of the mitigation zone



Source: Adapted from JNCC (2010).

The term **'soft-start'** refers to the gradual ramping up of piling power incrementally. The minimum soft-start duration is recommended as 20 minutes, over which time marine mammals can move away from the noise source, reducing likelihood of harmful exposure. If marine mammals are detected during soft-start, piling should cease where possible, or power should not be increased more until there has been no further detection for 20 minutes. When full power is reached, there is no requirement to cease piling or reduce power.

Acoustic deterrent devices (ADDs)

ADDs were developed as tools to warn species away from dangers like fishing gear, or to keep to them away from commercial fish stocks. Some emit sounds of an intensity that scares away animals. Others include recordings of an animal in distress, or of its predator, to deter species. ADDs are otherwise known as 'scrammers', 'seal scarers' or 'pingers'. There is usually a control unit and a transducer, where the control unit transmits bursts of audio signals that the transducer converts to an intense sound.

The use of ADDs to create a **temporary safety exclusion zone** (Figure 6c) around turbine locations could be an effective means of mitigating harmful construction phase impacts. The JNCC piling protocol also contains recommendations for the use of ADDs, including that they only be used in conjunction with visual and/or acoustic monitoring. The use of ADDs for this purpose is relatively novel and its effectiveness has currently been tested only for a few species. A study into the efficacy of 34 different ADDs found effective deterrence beyond 500 m for harbour porpoise, grey seal and harbour seal. The study also commissioned in-field testing of ADDs, providing recommendations for the types of ADDs, the duration of activation, mitigation personnel and equipment, and communication protocols.[399]

399 McGarry et al. (2017).

Figure 6c Temporary marine fauna exclusion zone around an offshore wind farm under construction using ADDs

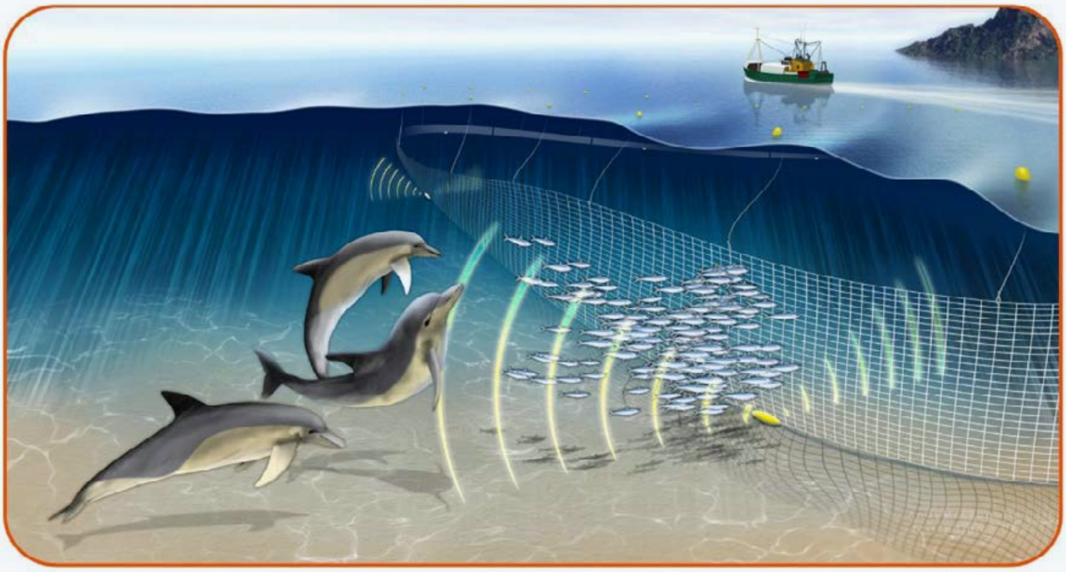


Illustration of how a pinger works. Image designed for the Cornwall Wildlife Trust by Andy McLaughlin at www.tcistudio.co.uk

Source: Ocean Science Consulting (OSC)

Methods to reduce underwater noise (abatement controls)

There are several other construction-phase methods for the reduction of underwater noise itself, as opposed to minimising species' exposure to it. Methods can be categorised as: i) source mitigation (methods that reduce sound directly at the source); 2) channel mitigation (methods that reduce the emitted noise in the water column; and 3) receiver mitigation (methods that prevent the receiver from being close to the sound.[400] An excellent summary of these methods is given in Thomsen and Verfuß (2019).[345]

Source mitigation includes:
Adjusting piling energy, noting that the minimum energy required varies according to the seabed type, and that the duration of the piling event is consequently extended (more strikes needed to install the pile).

Channel mitigation includes:
Reducing noise through reflection, absorption and shielding. Broadly, these are bubble curtains, 'shell-in-shell' systems, and noise damping systems. The **bubble curtain** technique is otherwise known as a pneumatic barrier, where bubbles of air are created through a nozzle hose on the seabed to rise up and surround the noisy operations and reduce noise levels beyond the curtain. This method has been found to be effective at the DanTysk offshore wind farm, Germany.[401] **Shell-in-shell** systems include noise mitigation screens – a double-wall steel tube into which the pile is inserted. The space between the walls is filled with air to reflect sound. There may also be a bubble curtain in this system. **Hydro sound damper (HSD)** methods involve surrounding the pile with HSD elements (foam plastic elements or gas-filled balloons) to reflect/absorb sound.

400 Thomsen & Verfuß (2019).
401 Dähne et al. (2017).

Cofferdams are single-walled steel tubes from which water is evacuated and into which the pile is inserted, such that the piling noise is reflected. Combinations of these measures may be used in construction, but almost always in conjunction with real-time field observations (marine mammal observers and passive acoustic monitoring).

Receiver mitigation includes:
Protocols, such as those discussed in the preceding paragraphs, where the objective is to encourage, or allow the opportunity for, the marine mammal to leave the impact area (e.g. monitored safety zones, soft starts and ADDs).

Drilling is also considered to be less noisy than piling, and there are drive-drill-drive and 'pure' drilling options.[402] Suction caisson[345] and other quiet foundation types avoid the need to drill/pile completely. Novel techniques that are, at the time of writing, not yet commercially available, include BLUE piling technology, whereby piling is achieved using the weight of a massive water column, in combination with gas combustion.

Cable installation

Installation methods for cable installation should be selected to reduce benthic disturbance, for example jet ploughing where seabed sediments are suitable (softer) (Box 13), and horizontal direct drilling as a lower-impact method of making cable landfall (Section 6.3.3).

Box 13 Installation of offshore wind cabling – minimising potential for habitat loss and disturbance

Overview: Generally, impact assessments consider the habitat loss associated with cable installation to be relatively small, and the disturbance arising from it temporary and short-term. However, experience in the UK indicates that this may not always be the case. In 2018, Natural England (a statutory advisor to the UK Government) published a summary of their ten years' experience of advising and making recommendations on UK offshore wind cabling,[403] indicating that in many cases, cable installation works have resulted in habitat disturbance and loss/change that was not assessed as part of the original project application.

Considerations: there is a considerable amount of cabling associated with an offshore wind farm. The **export cable** connecting the offshore and onshore substations is likely to traverse a significant distance, potentially over multiple seabed types, and the route may encounter obstacles. The point where the export cable makes **landfall** is also important – sensitive habitats should be avoided (Sections 6 and 9.1.2). The **array cable** connecting all the wind turbines to the offshore substation can also be extensive, more so when there are more turbines with bigger spaces between them. Thus, cable installation affects terrestrial, intertidal and marine habitats. The onshore cabling is usually installed first, then the export cable installation starts with the shore pull-in, and then moves offshore.[404]

Impacts and installation techniques: this is usually determined by the seabed sediment type. In addition to the area of habitat lost, there are impacts, including suspended sediment, habitat disturbance either side of the cable lay, and disturbance associated with the backfill/burial sediments.

402 Thomsen & Verfuß (2019).
403 Natural England (2018).
404 BVG Associates (2019).

The most commonly used methods are jetting, ploughing, trenching/cutting and vertical injector with either simultaneous lay and burial of the cable, or laying of the cable by a surface vessel and subsequent burial using another device. Cables are typically buried 1-4 m below sea bed for protection against fishing and anchoring).[193] The offshore cable route is always predefined to avoid sensitive habitats and obstacles, but before installation **seabed clearance** activities include grapnel runs to clear debris, boulder and unexploded ordnance removal, and removal of sandwaves to flatten the seabed or reduce slope. **Cable protection** is required at vulnerable locations such as at exposed areas where it cannot be buried). Methods include concrete mattresses, polyurethane mats, rock placement, grout/sandbags or frond mattresses. The installation of these materials may have disturbance impacts, such as temporary suspended sediment effects, and there are potentially effects associated with the introduction of these additional hard substrates. At **landfall**, the offshore cable usually terminates a short distance inland, or on the beach. The onshore cabling is generally buried in open trenches that are backfilled. Where the cable route meets sensitive habitats or obstacles that cannot be avoided completely, directional drilling may be used to pull the cable underneath.

Outcome of Natural England review: impacts not addressed in the original impact assessments tended to include those associated with: a different installation method; bringing vessels inshore; scour and secondary scour, and associated remedial work; requirement for more cable repairs or replacements than predicted; requirement for more/different cable protection types than predicted; requirement for more cable grapnel runs, sandwave and UXO clearance than predicted; a greater area of habitat/species impacted; and unclear monitoring and remediation planning.

Recommendations: based on their review, Natural England has made the following recommendations to industry:

- **Avoid cabling** in sensitive/protected habitats;
- **Change the approach to impact assessment** so that more information is collected and included in the early stages of project design, and so that data collection is more rigorous, with emphasis on the potential range and scale of impacts over the lifetime of the cable;
- **Avoid over-optimistic engineering predictions** by being realistic about the evidence gaps and the limitations of installation technology;
- Consider **mitigation** at much **earlier** stages of project planning; and
- Ensure that **monitoring improves the evidence base** on and recovery from cable installation impacts.

Construction lighting

The use of lighting offshore is influenced by navigational and safety considerations, varying depending on jurisdiction. However, light sources offshore can attract birds, particularly during nocturnal migration, and thus it is important to manage/control construction phase lighting including type, configuration, duration and intensity, to minimise this effect. A field study found that nocturnally migrating birds were disorientated and attracted by red and white light, but less so by blue and green light, and with a blue light birds generally followed a seasonally appropriate migratory direction.[405] Hence, changing the colour of lighting could minimise bird attraction. Lighting at offshore structures can also attract squid and light-sensitive fish at night. Light pollution onshore related to export cable installation may also present a risk to hatchling marine turtles, and fledgling seabirds may not take they first flight if their nesting habitat never becomes dark.[406]

It is therefore important to design lighting to manage (avoid and minimise) impacts. A useful example

405 Poot et al. (2008).

406 Commonwealth of Australia (2020); Defingou et al. (2019).

is found in Australian guidelines for best-practice lighting design,[351] which advocate managing artificial light to avoid and minimise disturbing species or displacing them from important habitat. It includes checklists for the management of artificial light and marine turtles, seabirds and migratory shorebirds, and incorporate the following design principles:

- Start with natural darkness and only add light for specific purposes;
- Use adaptive light controls to manage light timing, intensity and colour;
- Light only the object/area intended – keep lights directed and shielded to avoid light spill;
- Use the lowest intensity lighting appropriate for the task;
- Use non-reflective, dark-coloured surfaces (because polished, shiny or light-coloured painted surfaces reflect light); and
- Use lights with reduced or filtered blue, violet and ultra-violet wavelengths.

Section 6.5.2 provides more detailed information on lighting at offshore wind farms.

Operational controls

Vessels

In general, all vessels used in construction and operation/maintenance of a wind farm should conform to international standards under MARPOL,[407] which is considered as a minimum. Vessel activity in the wind farm area, and between the wind farm and the shore/port, should also be managed carefully to:

- Limit the number of vessel movements to and from the offshore wind farm area;
- Restrict/control vessel transit routes to avoid sensitive areas such as roosting/feeding habitats for birds);
- Limit vessel speed to avoid collisions with fauna. Vessels can reduce noise as well as the likelihood of colliding with marine mammals and turtles by travelling slowly *through* the water (as opposed to planning at speed across the surface), increasing the opportunity to see mammals in the water, as well as the opportunity for mammals to move away from the vessel; and
- Control the potential for accidental introduction of marine invasive alien species via vessel hulls and ballast water.

Other measures

Some examples of other abatement control and good environmental practice include:

- Implementing a safety zone around turbines during construction work for health and safety of personnel, and for **monitoring** of marine mammals and potential for vessel strike);
- Controlling accidental introduction of **invasive alien species** through hygiene/maintenance protocols for vessels and equipment, and contractors etc;
- **Managing waste disposal** and implementing a protocol for rapid management of any chemical leaks or spills; and
- **Enforcing good behaviour** by construction workers, including prohibition of hunting, trapping, fishing, and general harassment of wild animals.

Determining and maintaining the effectiveness of mitigation through operational and abatement controls is highly dependent on effective monitoring procedures and robust monitoring data. Spatial and temporal monitoring coverage must be appropriate for the scale of the potential impact and the planned mitigation measure.

Annex 1 summarises a list of good practice guidance documents to serve as a reference when developing the environmental practices to be applied during construction.

6.4.4. Restoration and rehabilitation

Some level of environmental damage is usually inevitable from construction of offshore wind developments, associated with project-related impacts that could not be completed avoided or minimised. Thus, restoration work to repair this damage will be required. For areas of temporary project footprint

407 International Convention for the Prevention of Pollution from Ships (MARPOL).

onshore, sensitive reinstatement to enable habitat to recover to its original condition and function should be undertaken in a phased approach concurrent with construction activities.

Post-construction restoration options for offshore wind farm developments are limited largely to the onshore components such as the construction laydown areas and the export cable landfall point. These areas should be returned to their undisturbed state as soon as possible after construction of the relevant component is complete. Examples of good restoration practices for the onshore components of a project include:

- Revegetating temporary-use and lay down areas as soon as reasonably practicable after construction activities are complete;
- Separately retaining and storing top soil and subsoil 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 contains natural seed stock) to facilitate natural revegetation of disturbed areas where reasonably practicable.

Offshore seabed disturbance should be restricted to the minimum area required for installation of a foundation, or for cable laying, and this should be factored into the project design and the selection of construction protocols to minimise impacts (e.g. through jet ploughing instead of cable trenching). For some marine ecosystems, such as seagrass meadows, restoration actions have been attempted with varying levels of success. Such efforts are often costly, small-scale and have unpredictable success rates, making avoidance and minimisation especially important.[408]

Offshore wind farm developments, particularly where components are located in degraded coastal or sea areas such as heavily-trawled areas, are encouraged to take further steps to employ PCAs (Section 7.2) to enhance the habitat on site to create benefits for biodiversity.

6.5 Mitigation in the operational phase

6.5.1. Overview

Once commissioned, offshore wind turbines are expected to operate continuously for a lifespan of approximately 25 years without major life extension upgrades.[409] Electricity generated by the wind farm is sold to customers, and the income used for loan repayment, operational and maintenance staff salaries, utility charges, landowners rent, local authority rates, project insurances, mitigation and offset measures, etc.

Offshore wind farms have generally higher maintenance and servicing requirements than their onshore counterparts, which is largely due to the harsher marine operating environment. Operational support is provided continually (24 hours per day, every day of the year), including weather monitoring and live turbine monitoring. Sometimes support is remote, via the wind farm supervisory control and data acquisition (SCADA) system.[410] The operational phase involves regular scheduled inspection and maintenance visits to the offshore infrastructure. These visits require transfer of personnel and equipment to the turbines and offshore substation, which means there are also significant health and safety considerations. Unscheduled maintenance is also conducted when issues or failures arise.

6.5.2. Minimisation measures

Minimisation measures in the operational phase involve implementing physical, abatement and operational controls. Commissioning of wind turbines

408 Bayraktarov et al. (2016); Floor et al. (2018); Katwijk et al. (2015); Unsworth et al. (2019a); Unsworth et al. (2019b).
409 BVG Associates (2019); Crouse et al. (2019).
410 BVG Associates (2019).

is often a rolling process with individual turbines, or groups of turbines, installed and commissioned as the construction phase progresses. This means operational mitigation measures need to be in place, at the appropriate scale, from the commissioning of the first turbine (i.e. as soon as turbine blades begin rotating).

Minimisation in the operational phase of an offshore wind farm can be categorised into three types:

- Minimisation by **physical controls:** involves modification to standard infrastructure, or the standard operation of infrastructure, to reduce impacts on biodiversity;
- Minimisation by **abatement controls**: involves taking action to reduce emissions or pollution (dust, light, noise and vibration, solid/liquid waste) that could negatively impact biodiversity and ecosystem services;
- Minimisation by **operational controls**: involves managing and regulating activity and movement of operations and maintenance contractors and land/site managers.

Physical controls

Collision risk

A primary biodiversity risk during the operational phase is the potential for birds and bats to collide with turbine blades. Collision/electrocution associated with onshore grid facilities is also an important risk factor.

With respect to collision with blades, the most effective measure is to shut down turbines temporarily when priority species are at risk. This could be for pre-defined periods and could comprise some or all of the following:

- **Time of the day/night**, for example time of species peak diurnal activity;
- **Ambient environmental factors**, for example wind speeds and temperature, which are particularly relevant for bats; or
- **Seasonal**, for example during bird/bat migration seasons.

Alternatively, or additionally, turbine shut-down could be 'on demand' in real time in response to a pre-determined set of criteria based on the potential occurrence of high-risk scenarios such as large flocks of priority bird species spotted approaching wind farm.

Where priority species are only present around turbines during clearly demarcated periods or conditions, pre-defined shutdown for these periods will effectively avoid impacts. For example, shutdown can occur for migratory birds that travel through a wind farm in predictable pulses. This approach also requires minimal on-going surveillance on-site. However, it may often have relatively high economic cost through loss of power generation.

Where species presence is less predictable, real-time shutdown on demand is likely to be a more practical approach. Shutdown on demand is likely to reduce but not completely prevent impacts. There may also be significant on-going surveillance costs, for staff and/or equipment.

Shutdown on demand approaches for birds

'Shutdown on demand' (SDOD) is based on real-time observations of bird activity in the wind farm area. SDOD approaches for birds rely on one or more of the following: (i) field observers; (ii) image-based systems; and (iii) radar systems, all of which are more challenging to establish/implement in the offshore environment and are far less well-tested than for onshore wind farms.

Observer-led SDOD requires experienced bird field surveyors to be stationed at vantage points within and in the vicinity of the wind development area. Using pre-established criteria, observers identify priority bird species and track their flight path. If a collision appears likely, observers notify the wind farm control centre to have the 'risk turbine(s)' immediately shut down. The turbine(s) will only be re-started when the risk of collision has passed.

The number and location of observers must be adequate to allow 'at-risk' birds to be detected and identified in a timely manner, so that turbines can be stopped before the birds reach them. The requirements will vary for different wind farms depending on size, turbine layout, and the size, flight speed and flight direction of priority species. This approach may not be appropriate for some priority species if they are too small or if flight is too fast for them to be identified in time for turbines to shut down before individuals enter the collision risk zone.

Clearly, such observer-led methods are constrained in the offshore environment because of the difficulties of accessing and remaining on site, and the later-stage issues of potentially stationing observers on turbine/infrastructure platforms. However, they may be more feasible for nearshore wind farms where there are suitable elevated coastal vantage points.

Image-based systems use cameras to capture digital still images or video sequences of birds, while **radar systems** identify flying animals, distinguished roughly by size, based on echo characteristics and/or wing beat frequencies. These systems can be paired with automated analysis of the images by a computer software. Operators can activate shutdown after receiving real-time information from the system or, alternatively, shutdown can be automated by the system itself. Some examples of automated image detection and radar technologies for SDOD are given in Table 5-4.

Owing to current technological limitations, it will usually be advisable to use image-based and radar systems in support of human observers, rather than alone – which again is a limitation for offshore wind projects. For example, radar systems can only distinguish object size classes rather than species and not between species or species-groups of interest, unless their size is different from all other species present. Furthermore, the effectiveness of technology to support SDOD procedures is still unproven. For a detailed description of each system, including their advantages and disadvantages, as well as resources, see Annex 1.

Multi-sensor monitoring systems are thus likely to be most promising for offshore wind. Systems, such as MUSE,[411] integrate radar and digital camera with the wind farm control software, enabling continuous collection of video data on seabird flight behaviour at operational wind farms, with software for automated tracking and geo-referencing of species-specific track data. Controlled and un-supervised wind farm curtailment (shutdown) is also possible.

Mitigation approaches for bats

Research from the Netherlands into how best to study bat behaviour near offshore turbines has shown promising results using a stereoscopic setup with thermal cameras, acoustic bat detectors and tailored 3D analysis tools.[412] Another study concluded that telemetry can be successfully used to study both migratory movements of bats over land and sea, and the behaviour of individual bats near an offshore wind farm, but that for long-term monitoring of multiple individuals, the only feasible option is to establish a grid of stationary receivers.[413]

There are no specific bat collision detection systems operational at present, but some bird detection systems can detect bat fatalities as well (Table 6-4). Other than direct collision, bat fatalities at wind turbines could also be caused by 'barotrauma' – large differences in air pressure around the turbine, close to the blades,[414] although there is little empirical evidence for this (Section 6.2.1). Therefore, since some bats could be killed without actually colliding, systems with a camera component are the best available option available for monitoring impacts.[415]

Finding bat fatalities at sea is a considerable, potentially impossible, challenge. Currently, given the uncertainties regarding bat presence and behaviour offshore, and the paucity of the dataset for bats and offshore wind impacts, there is no process for predicting bat fatalities or displacement effects. Hence, there are few documented mitigation protocols for offshore projects except where bats are better studied such as in Europe and North America. Site decisions from consented Dutch offshore wind farms have included regulations for mitigation of bat collision risk (among other things) which considers

411 Skov et al. (2018).
412 Lagerveld et al. (2017).
413 Ibid.
414 Dirksen (2017).
415 Ibid.

the following during the period of 15 August – 30 September:[416]

- Turbine cut-in limited to five metres per second wind speed (at axis level), from one hour after sunset to two hours before sunrise;
- If wind speeds during this period are below five metres per second, the number of rotations per minute per wind turbine should be less than one; and
- Developers are also required to report on the implementation of this mitigation measure.

Onshore, there is substantial evidence that insectivorous bat activity around wind turbines, and associated collision fatalities, are highest at low wind speeds. An effective minimisation measure could thus be to increase the wind speed at which turbines become operational (the 'cut-in speed'). Below this speed, depending on model, the turbine blades are either stopped from rotating or 'feathered' (pitched parallel with the wind direction), so that they spin very slowly if at all, with no energy output. Thresholds for turbine cut-in speeds need to be based on site-specific monitoring results. Cut-in speeds can be adjusted for site-specific bat activity peaks considering a number of parameters:

- Wind speed (m/s measured at nacelle height);
- Time after sunset/before sunrise;
- Month of the year;
- Ambient temperature; and
- Precipitation (mm per hour).

Either increasing cut-in speeds, stopping/feathering blades, or both, are proven to reduce bat fatalities at onshore wind farms. Studies in North America[417] and Europe[418] showed that applying these measures resulted in at least 50% reductions in bat fatalities. Resulting power losses and economic costs were revealed to be low, resulting in as little as a 1% decrease in total annual output.[419] These measures do not apply to non-echolocating plant-visiting bats. While evidence shows that certain species could be vulnerable to colliding with wind turbines,[420] there is no empirical evidence for mitigation measures that are proven effective in minimising plant-visiting bat fatalities during operation. Additional studies in the future may identify new measures to reduce collision risk of this group during the operational phase.

Other approaches to reduce collision risk

Other measures recommended mainly focus on **modifications to wind turbines** themselves, and to **overhead transmission lines associated with the onshore electrical infrastructure**, to reduce risk of bird and bat collisions (Table 5-2), including:

- Painting one turbine blade to increase visibility to birds;
- Using ADDs;
- Installing bird flight diverters on overhead powerlines (Table 6-3);
- Wildlife-safe design or retrofitting power-line wires and poles; and
- Altering the configuration of overhead powerlines to increase visibility to birds.

Other measures have been proposed but do not appear to be as effective and/or have associated unpredictable effects.[421] These include:

- Auditory deterrents for birds such as warning sirens. This approach is being trialled with the DTBird system (Table 6-4), and while trial results are promising for some species in some locations, this method has yet to be demonstrated as generally effective for a broad range of species and sites. The loud noise, audible to humans, means it may have limited deployment opportunities;
- Visual deterrents such as lasers;
- Other measures that aim to increase turbine visibility, including markings on the ground and some turbine blade patterns such as

416 Rijkswaterstaat/Ministry of Infrastructure and the Environment of the Netherlands (2016).
417 Arnett et al. (2013), (2011); Baerwald et al. (2009).
418 Rodrigues et al. (2015).
419 Arnett et al. (2013).
420 Ibid.
421 Arnett & May (2016); Drewitt & Langston (2006); Marques et al. (2014).

square-wave and black-and-white bands and use of ultraviolet reflective paint; and

- Adjusting the frequency, colour or wavelength of flashing aviation warning lights on turbines.
- Additional studies in the future may find these measures to be effective for other specific species or identify new measures to reduce collision risk.

Table 6-2 Summary of other measures suggested for minimising bird and bat collisions at operational offshore wind farms

Measure	Receptor	Description	Examples evidencing effectiveness
Wind turbines			
Increasing visibility of rotor blades	Birds	Increasing the visibility of turbine blades (and towers) could reduce the potential for collision, and could be done by painting blades in a high-contrast colour to reduce 'motion smear' [422] or in ultraviolet paint. It is also suggested that turbine blades should not be 'pure white' or 'light grey', since these colours attract insects and may increase insectivore activity. There may be regulatory, engineering and societal constraints to applying such measures.[423]	This measure is apparently untested for offshore wind farms. Painting two-thirds of a single blade of each onshore wind turbine black in colour in the Smøla wind farm in Norway reduced white-tailed eagle (*Haliaetus albicilla*) fatalities by 100% over unpainted controls.[424]
Installation of acoustic deterrent devices	Bats	This measure involves the installation of acoustic devices on the turbines. Such devices emit high frequency sounds within the range of bat call frequencies to mask echo perception, or create an airspace around the rotor swept area that bats might avoid. Evidence of the effectiveness of this measure is limited to onshore North America, but is currently being trialled elsewhere.	Acoustic methods are frequently used to study bats offshore, but there is little evidence of the use of ADDs in offshore wind farms for bat deterrence. Onshore, at Los Vientos wind farm (Texas, USA), acoustic devices resulted in a 50% reduction in overall bat fatalities with varying species-specific responses. There was a 54% and 78% reduction in fatalities for the Brazilian free-tailed bat (*Tadarida brasiliensis*) and hoary bat (*Lasiurus cinereus*), respectively. Species-specific differences may be linked to differences in echolocation frequencies. Acoustic devices appeared to be less effective for bats with high frequency calls.[425]
Overhead power lines onshore			
Installation of bird flight diverters	Birds	Attaching devices (typically flappers, balls or spirals) to transmission lines to increase their visibility. Evidence for the effectiveness of this measure is fairly robust (see Table 6-3 for a summary of the different design options and examples of effective application).	An analysis of 35 studies on the effectiveness of wire-marking in reducing bird collisions with power lines revealed that average collision mortalities was reduced by 50%, with the type of device having no influence on this effect.[426]

422 Hodos (2003); Hodos et al. (2001).
423 Harwood & Perrow (2019), which also contains a useful review of methods for increasing turbine visibility to reduce collisions.
424 Dixon et al. (2018); May et al. (2020).
425 Weaver (2019).
426 Bernardino et al. (2019).

Wildlife-safe design or retrofitting power-line wires and poles	Birds	Designing low- or medium-voltage power-lines, or adding insulation to existing poles and wires, to reduce the risk of electrocution of birds or other wildlife from contact. Evidence proving the effectiveness of this measure is robust.	In Mongolia, retrofitting of insulation on low-voltage power pylons resulted in an estimated 85% reduction in mortalities.[427]
Altering transmission line configurations	Birds and bats	Measures to change the design of transmission lines to reduce bird collisions aim to reduce the vertical spread of lines, increase the visibility of lines, and/or decrease the span length. Specific measures could include: (i) reducing the number of vertical wire levels by adjusting the conductor heights to reduce the number of potential collision points; (ii) stringing wires as low as possible; (iii) keeping wire span lengths as short as possible to minimise line height as birds usually respond to seeing lines by increasing height; and (iii) using wires with a thicker diameter or bundling wires to increase visibility.	While these measures are generally agreed upon and recommended, further scientific evidence is needed to clearly demonstrate their effectiveness.[428] Electrocution risk to fruit bats was found to be almost zero for powerlines with wires oriented horizontally. Vertically oriented powerlines killed close to one individual per km of powerline.[429]

427 Dixon et al. (2018).

428 Bernardino et al. (2018).

429 Tella et al. (2020).

Table 6-3 Bird flight diverter designs for overhead transmission lines

Design	Practical and ecological considerations	Evidence of effectiveness
Flappers (mobile)	There is a wide variety of sizes and configurations – all of which have similar levels of effect. Very visible because they can pivot over 360° when windy, and some contain reflective panels or iridescent components making them visible at night. May malfunction (either break or fall off) in locations with sustained high wind speeds or extreme temperature conditions. Can be installed on operational transmission lines using drones, or from the ground using a hot stick.	In California, installation of flappers on spans reduced avian collisions by 60% when compared with non-marked spans.[430] In Nebraska, installation of flappers resulted in >50% reduction in sandhill crane deaths compared to spans without flappers.[431]
Spirals (static)	There is a variety of dimensions for different line widths. Likely the most durable option, with no moving parts, but may be less visible to some species for the same reason. Very challenging to install once the transmission line is operational, and installation is labour intensive. Not recommended for installation on transmission lines >230kV due to corona effects.	In Indiana, waterfowl collisions were reduced by 73% and 37.5% for small and large spirals respectively, on marked versus unmarked lines.[432] In the UK, installation of large spirals reduced average springtime collisions from c. 15 to <1 mute swan between years.[433]
Night-lit devices	Important where at-risk species move by night. New technology which has only been trialled on one species at one site – effectiveness unknown for other species or locations.	Installation of near-ultraviolet lighting that shines on powerlines in Nebraska, USA reduced sandhill crane collisions by 98%.[434] In South Africa and Botswana, bird flapper and flight diverters fitted with Light Emitting Diodes (LED) have been installed to reduce flamingo (*Phoenicopterus roseus* and *P. minor*) and blue crane (*Anthropoides paradiseus*) collisions. Anecdotal evidence points to the effectiveness of this mitigation measure.[435]
Aviation balls	May not be suitable for areas where ice or high winds are expected, due to increased stress on the line. Visually more obvious than other options. More costly per unit than other options, but greater spacing means overall costs may not be more costly. Labour-intensive to install on existing line. Use may be limited by aviation regulations.	Installation of 30 cm diameter yellow balls with a black stripe on spans in Nebraska reduced collisions of sandhill cranes by 66% compared with unmarked spans.[436] In South Carolina, there was a 53% reduction in all species' collision mortalities at spans with yellow balls compared with unmarked spans.[437]
Increasing wire thickness	Much more expensive than standard diameter wire, and requires heavier-duty supporting infrastructure. Extremely durable, with quoted life-spans of >40 years.	Anecdotal evidence of effectiveness, but unproven in rigorous field trials.

430 Yee (2008).
431 Murphy et al. (2009).
432 Crowder (2000).
433 Frost (2008).
434 Dwyer et al. (2019).
435 Smallie (2008); van Rooyen & Froneman (2013).
436 Morkill & Anderson (1991).
437 Savereno et al. (1996).

Table 6-4 Selected examples of automated image detection and radar technologies for shutdown on demand (SDOD)*

Technology	Description	Application	Demonstrated use & effectiveness
Camera technology			
DTBird®	Uses a suite of daylight and/ or thermal imaging cameras mounted on individual turbines or similar structures	• Birds only. • Once targets are identified, the system can issue a warning sound or automatically shut down turbines, based on preset criteria and distance from turbine). • Detection distance is related to bird size. Best case scenario for a golden eagle around ~600 m during the day and ~200 m at night.	A DTBird system was installed in 2015 for three years at offshore Platform FINO 1, a research platform in the North Sea, immediately in the vicinity of the operational offshore wind farms Alpha Ventus, Borkum Riffgrun I and Trianel Windpark Borkum. Most instances of DTBird systems use are at onshore wind farms: Detectability was shown to be >80% at an onshore test site in California, USA.[438] Warning sounds reduced flights in the collision risk zone in trials in Sweden and Switzerland by 38-60%.[439]
IdentiFlight	Uses a suite of daylight and/ or thermal imaging cameras mounted on individual turbines or similar structures	• Birds only. • Imaging is linked to an algorithm to classify objects – has the potential to be species-specific. • Fully integrated with SCADA for automated shut down – no need for human involvement. • Has an operational range of 1,000 m.	Has a 96% detection rate (i.e. missed 4% of all bird flights) with a false negative rate of 6% (classifying eagles as non-eagles) and false positive rate of 28% during onshore trials in Wyoming, USA.[440] Installed at onshore wind farm sites in Australia (for wedge-tailed and white-tailed sea eagles), northern Germany (for red kites) and multiple USA sites.
Radar technology			
Robin Radar Max©	Uses radar to provide real-time detection and 3D tracking of birds	• Birds only. • Has a ~15km maximum detection distance with unrestricted line of sight. • Shut down can be fully automated using predefined rules, and has the potential to be species-specific. • Expensive to purchase, at ~ >US$ 500,000. • Use may be restricted by national military or aviation regulations.	Deployed at the Tahkoluoto offshore wind farm in Finland, to prevent collisions from white-tailed sea eagles and black-backed gull.[441] Operational at the Kavarna wind farms in Bulgaria, where it automatically shuts down turbines for priority species, particularly migratory species.
STRIX Birdrack©	A radar system to automatically detect and track individual birds or bats	• Birds and bats. • Cannot identify individual species – can detect size class only. • Has a detection range of up to 12 km, depending on target size. • Shut down can be fully automated using predefined rules or manually controlled. • Radar use may be restricted by national military or aviation regulations. • Has not been used in isolation, always in combination with observers.	Birdtrack was used at the Barão de São João wind farm (Annex 2, case study 13) with zero fatalities over five years (note that radar was used in combination with observers). Deployment in Egypt has resulted in fatality levels held at 5–7 fatalities per year, from around 370,000 birds passing through the wind farm each season.[442]

** Note: This list is not exhaustive. Other technologies are available and in the process of development.*

438 H.T. Harvey & Associates (2018).
439 Riopérez et al. (2016).
440 McClure et al. (2018).
441 Södersved (2018).
442 Tomé et al. (2018).

Abatement controls

Operational phase lighting

Further to the information presented in Section 6.4.3 (managing lighting design), lighting impacts should also be managed and mitigated during the operational phase to the extent possible with respect to aerial and marine safety, and within the limits of national legislation. The impact in the key operational phase is the potential for bird collision with turbines as a result of attraction to lighting.

Studies suggest that the most effective means of mitigating collision risk associated with offshore lighting involves restricting lighting to a minimum using blinking light as opposed to continuous light, and if continuous light is required using red light.[443] Studies of onshore infrastructure have found that towers lit at night with only flashing red or white lights had significantly fewer bird fatalities than towers lit with a combination of steady and flashing lights,[444] and that flashing red lights should be used on turbines, rather than steady lights.[445] Other work indicates that violet and ultraviolet light could also be effective in reducing bird activity.[446]

Other measures

Minimisation through **abatement controls** also includes control of noise, accidental chemical spill from oil or fuel, and other waste. Some examples of good environmental practices include **managing waste disposal** and implementing a protocol for rapid management of any chemical leaks or spills. Annex 1 summarises a list of good practice guidance documents to serve as a reference when developing the environmental practices to be applied during construction.

Operational controls

Vessels

Vessel activity in the wind farm area, and between the wind farm and the shore/port should be managed carefully during the operations phase, as for the construction phase (Section 6.4.3).

Controls associated with onshore facilities

Operational controls for the onshore component of offshore wind farm development involve the onshore substation/grid connection, and the port/harbour area designated for offshore wind farm maintenance logistics. Managing and regulating activity and movement of operations and maintenance contractors and site managers is also important to minimise potential for impact. Land management is important at onshore facilities, including: waste management and minimising food resources and availability for scavenging species; and establishing or altering vegetation/habitat conditions to reduce suitable foraging and nesting habitat.[447,448,449] It is also important that good behaviour by contractors is enforced, including prohibition of hunting, trapping, fishing, and general harassment of wild animals.

443 Rebke et al. (2019).
444 Gehring et al. (2009).
445 Kerlinger et al. (2010).
446 May et al. (2017).
447 Mammen et al. (2011).
448 Scottish Natural Heritage (2016).
449 Martin et al. (2012).

6.6 End-of-life

6.6.1. Overview

At the end of the designed operational life of an offshore wind farm, the options, broadly, are to: (i) extend the operational life of the existing assets; (ii) repower the site (Section 6.6.3); or (iii) fully decommission the site.[450] Very few offshore wind farms have yet reached closure and decommissioning (or repowering) stage. Both repowering and decommissioning provide opportunities to undertake further mitigation and are the focus of this section.

6.6.2. Repowering

To date, there has been limited testing of the potential to repower offshore wind farms – most projects are currently operating well within their projected lifecycle. One small offshore project is known to have been repowered thus far.[451]

There are two types of repowering:

- **Partial**: involving the replacement or reconditioning of less durable parts of the wind farm, retaining cables, foundations and towers but not changing the nacelle or the blades;
- **Full**: potentially involving a reduction in the total original number of turbines whilst retaining the operational capacity of the wind farm by using newer/larger turbines, or completely replacing all the turbines.

Avoidance through project design

Considerations for the mitigation of potential biodiversity impacts are similar to those in the construction and decommissioning phases, depending on the type/amount of work required. Crucially, if the turbines are replaced with larger ones, a **re-assessment of the potential for bird collision risk** will be necessary. This may mean that different or additional collision risk mitigation is required, with subsequent amendments to the monitoring protocol.

The underwater noise impacts of turbine replacement should also be reviewed. Foundation installation may or may not be involved; if not, the noise impacts of repowering are not likely to be as extensive as the original construction impact. The noise associated with jack-up vessels and vessels with dynamic positioning systems should also be evaluated with respect to adverse effects on marine mammals. Mitigation options for any related impacts are likely to be the same as those employed during construction – involving marine mammal observers and careful management of ramp-up to full noise (Box 12).

The potential for repowering a project is difficult to determine early on, being dependent on the age and condition of the offshore infrastructure at the repowering decision point, and on the available turbine technology at that time. For example, in the UK, it is less likely that some of the older near-shore wind farms will be repowered because either some of these turbine types currently installed are no longer available, which are relatively small compared to those available at present, or the existing foundations are unlikely to be capable of supporting more powerful (larger) new turbines.

Turbine technology has evolved rapidly since the early days of offshore wind. Projects currently in planning for locations further offshore are necessarily required to be more robust and can draw on lessons learned from engineering of earlier projects. Thus, it may be more likely that recently commissioned and upcoming offshore wind farm projects could eventually be repowered.

6.6.3. Decommissioning

The decision to decommission could be in part driven by the offshore wind farm site lease, depending on seabed ownership considerations. Decommissioning is the removal or making safe of offshore infrastructure at the end of its useful life.

450 BVG Associates (2019).

451 Turbines at the Bockstigen Wind Farm in Sweden were partially repowered in 2018 by replacing the nacelles, blades and control systems of five 20-year-old turbines with components sourced from five refurbished turbines. The original turbine towers, foundations and transmission cables were re-used. For further information, please see: greentechmedia.com.

Impacts during the decommissioning phase are likely to include:[452]

- Visual and acoustic disturbance due to dismantling activities;
- Disturbance from vehicle and machinery operation during dismantling activities;
- Loss of habitat (e.g. resting areas on above-water infrastructure, or feeding areas on below-water infrastructure);
- Emissions (noise, dust, light); and
- Water column turbidity due to sediment disturbance.

Given that few projects have yet been decommissioned, projects have long lifecycles and most are some time away from this stage, there are several uncertainties regarding the process, particularly for large projects: [453]

- The regulatory environment (in many jurisdictions, regulations regarding offshore wind farm decommissioning are at present limited);
- Strategies for recycling components;
- The economic case for recycling and reuse, which will depend closely on the climate at the time of decommissioning including the volatility of scrap value; and
- The consequences of removal of habitats that may have developed on anthropogenic structures.[454]

The decommissioning phase could involve the complete removal and shipment to shore of the following components:

- Turbine tower, nacelle and rotor;
- Foundation piece(s) (although it may be more appropriate to cut these off at seabed level and make safe);
- Cables; and
- Substation.

The onshore components of the project (buildings, substation and cables, etc.) may also need to be dismantled and removed.

Avoidance and minimisation

Decommissioning is essentially the reverse of the construction phase, employing many of the same procedures and equipment used during construction. Hence, as in the construction phase, avoidance through scheduling (Section 6.4.2) and minimisation by operational and abatement controls (Section 6.4.3) will also generally apply here. However, offshore the process is time consuming and challenging due to weather conditions and distance from shore. Heavy lifting of large components offshore is risky, and so the preference is often to maximise onshore disassembly.[455]

Other considerations for this phase include environmental surveys before decommissioning, activities at the decommissioning port, and waste management, reuse and recycling. Mitigation measures include:

- **Reviewing** the monitoring dataset accumulated over the project lifecycle and undertaking field surveys, if needed, to confirm the sensitive species for consideration during decommissioning. It is conceivable that the 'reef' or 'refuge' effect could be such that straightforward infrastructure removal is not appropriate;
- **Avoiding** decommissioning work during **sensitive periods** of species' lifecycles such as breeding and migration periods;
- **Minimising** the potential for marine mammal vessel strike and vessel noise (Section 6.4.3);
- **Minimising** seabed disturbance during foundation and cable removal (likely associated with the method of removal, and for example involving a jack-up rig for heavy lifting);
- **Minimising** underwater noise impacts on marine mammals associated with infrastructure removal procedures such as underwater cutting (Box 13);
- Accounting for and addressing potential social and ecosystem **service** impacts arising from biodiversity mitigation;

452 Defingou et al. (2019).
453 Topham et al. (2019).
454 Birchenough & Degraer (2020).
455 Topham & McMillan (2017).

- **Managing** waste disposal and implementing a protocol for rapid management of any chemical leaks or spills;
- Ensuring best-practice for reuse, recycling or disposal of decommissioned components;
- Enforcing good behaviour by decommissioning workers, including prohibition of hunting, trapping, fishing, and general harassment of wild animals.

Restoration

After decommissioning, the site should be reinstated to its original state, or better, as far as possible, in accordance with national requirements and/or site lease agreements with site owners. For onshore components, this is relatively straightforward (restoration) (Section 6.4.4). However, if a significant ecological community has developed in the offshore wind farm area as a result of the introduction of new hard substrate (Table 6-1), it may be preferable to leave some infrastructure in place.

The principles of offshore wind farm decommissioning are not dissimilar to other energy facilities, onshore and offshore. Hence, general good practice mitigation measures will be relevant.

6.7 Summary of mitigation approaches for offshore wind farm projects

Table 6-5 summarises the mitigation approaches addressed in this chapter for offshore wind.

Table 6-5 Summary of mitigation approaches for offshore wind farm development

Project phase	Mitigation Hierarchy	Mitigation approaches
Site characterisation	Avoidance and minimisation	Scheduling: changing the timing of survey activities to avoid disturbing biodiversity during sensitive periods Operational controls to manage and regulate contractor activity (e.g. controlling vessel movements)
Project design phase	Avoidance and minimisation	Micro-siting: changing the layout of project infrastructure to avoid sensitive areas Selecting or designing project components to avoid or reduce impacts such as quiet foundations Re-routing, marking or burying onshore powerlines to avoid collision risk
Construction phase	Avoidance	Scheduling: changing the timing of construction activities to avoid disturbing biodiversity during sensitive periods
	Minimisation	Abatement controls to reduce emissions and pollutants (e.g. selecting construction methods to minimise underwater noise impacts) Operational controls to manage and regulate contractor activity (e.g. controlling construction/installation vessel movements and managing lighting)
	Restoration and rehabilitation	Repair of degradation or damage to biodiversity features and ecosystem services from project-related impacts that cannot be completely avoided and/or minimised (e.g. revegetating onshore laydown areas or restoring coastal intertidal habitats disturbed during export cable installation).
Operational phase	Minimisation	Physical controls involving modification to standard infrastructure, or the standard operation of infrastructure, to reduce impacts (e.g. through shutdown on demand to minimise collision risk) Abatement controls to reduce emissions and pollutants (e.g. by managing maintenance lighting) Operational controls to manage and regulate contractor activity (e.g. through controlling maintenance vessel movements)
End-of-life	Avoidance	Scheduling: changing the timing of decommissioning activities to avoid disturbing biodiversity during sensitive periods such as breeding seasons
	Minimisation	Abatement controls to reduce emissions and pollutants created during decommissioning, such as cutting of sub-sea infrastructure Operational controls to manage and regulate contractor activity (e.g. vessel speed regulation) and minimize risk to biodiversity such as marine mammal strike
	Restoration and rehabilitation	Consider (if legislation allows) leaving infrastructure in place if there is a biodiversity/ecosystem services benefit such as the reef effect associated with foundation/scour protection Revegetation of disturbed areas onshore as they become available, using top soil and indigenous plants from the site where possible.

Part III

Implementation of biodiversity offsets and proactive conservation actions

Assessment, monitoring and evaluation

Process for aligning with good practice

Supply chain stewardship

7. Implementation of biodiversity offsets and proactive conservation actions

7.1 Overview of biodiversity offsets

Biodiversity offsets are measures taken as a last resort to compensate for any residual significant, adverse impacts that cannot be avoided, minimised and/or restored (Box 16).[456] Offsets should be designed to meet a specific and measurable goal that directly relates to a project's residual impacts, aimed at achieving a no net loss or a net gain for the biodiversity they target (Section 2.5 on biodiversity goals).

Offsets are the last step in the mitigation hierarchy, and a last resort after avoidance, minimisation and restoration have been implemented to the maximum extent feasible. Offsets frequently are complex to plan, challenging to implement, expensive and uncertain in outcomes. In some situations, implementing offsets may be inappropriate or impossible (Box 14). For wind and solar projects, offsets bring some particular challenges:

- Residual impacts can be difficult to predict, particularly before, but also during early project construction and operations. This is particularly so in data-poor regions (including many offshore environments) and/or where there is as yet limited experience with wind and solar and their effects on local species. Robust, long-term field data collection is therefore needed to estimate and track project impacts and the effectiveness of mitigation. Monitoring during operations may show up unanticipated impacts that require additional mitigation, possibly including offsets.
- For migratory species (many birds, bats and marine species), viable offset sites may be far from the development site, and potentially in different jurisdictions (Box 14). This can make it challenging to secure offsets, and support from stakeholders who see the impacts but not the benefits. For instance, many migratory bird species may encounter wind farms on passage, despite having no resident populations in those countries. For such species, local options for offsets may be few and there may be a need to implement offsets in either their breeding or wintering grounds.
- Verification of offset gains may be challenging, due to the long generation time and large-scale movements of many species at risk.

Fortunately, early and effective project planning can often eliminate the need for offsets for renewable projects (Section 3). However, offsets may be required where projects have unanticipated impacts, or predicted impacts that for one reason or another cannot be fully avoided, minimised or restored.

456 IUCN WCC (2016). There are other definitions for offsets, although they all involve actions that provide measurable gains to compensate for significant residual impacts after application of avoidance, minimisation and restoration measures.

Box 14 Offsets for migratory species

Migratory birds and bats are particularly susceptible to wind-related impacts, some of which can be difficult to mitigate fully without offsets. These species may be subject to multiple threats along their migration routes. Threats are not evenly distributed and can be most acute at particular crunch points along the migratory range, far from the project site such as at important stopover sites for waders threatened by land reclamation. Offset interventions that aim to tackle threats to these areas can provide significant conservation benefits to the species concerned and allow developers to achieve net gains. Biodiversity offsets across borders have yet to be tested but could be considered as part of international species conservation initiatives, under frameworks such as the Convention on Migratory Species.

Box 15 Limits to biodiversity offsets

There are some circumstances in which biodiversity offsets are not feasible, or not appropriate. The technical requirements for offsetting may not be met (e.g. it is not possible to protect or restore the target species or ecosystem elsewhere), or an offset is theoretically possible but the risk of failure is very high. In these circumstances, offsets cannot be used, meaning that the project as designed should not proceed.

IUCN's offsets policy states that, "at a minimum, offsets must not be used:

- Where impacts are likely to lead to a high risk of driving one or more previously non-threatened species and/or ecosystems into the IUCN Red List Categories of Vulnerable, Endangered, Critically Endangered, Extinct in the Wild or Extinct, or driving one or more previously threatened species and/or ecosystems into IUCN Red List Categories of higher threat;
- Where the success of the offset action is highly uncertain due to a lack of knowledge;
- Where there is a substantial risk that investment generated by offsets might substitute for, rather than add to, other investment for conservation;
- Where the exchanges involved in the project's residual losses and the predicted offset gains are considered socially or culturally unacceptable to relevant stakeholders;
- Where the values that will be lost are specific to a particular place, and therefore cannot be found elsewhere and adequately protected or re-created;
- Where the time lag between the residual loss of biodiversity caused by the project and the gains from the offset causes damage that cannot be remediated and/or puts biodiversity components at unacceptable risk;
- When impacts will occur in internationally and nationally recognised 'no-go' areas, such as natural or mixed World Heritage Sites and protected areas, that are recognised as IUCN categories I, II, III and IV;
- When such action is considered incompatible with IUCN Resolutions and Recommendations". [457]

457 IUCN (2016).

There is a diverse range of possible offset activities, which can be delivered either on-site or (more typically) in another location. In general terms, offsets are divided into two types:

- **Restoration offsets**, which aim to remediate past damage to biodiversity (not caused by the development project in question) (Annex 2, case study 17). It should be noted that restoration offsets (which aim to *compensate* for project impacts) are different to the restoration step of the mitigation hierarchy (which aims to *reduce* residual project impacts).
- **Avoided (or averted) loss offsets**, which generate biodiversity gains relative to a credible reference scenario (the 'counterfactual') by protecting or maintaining existing biodiversity features that would otherwise be lost or degraded (Annex 2, case study 18). For example, deaths of birds of prey could be averted by retrofitting of non-project power lines to prevent electrocutions, removal of carcasses from roads to prevent raptor collisions with vehicle traffic, or implementation of anti-poisoning programs to reduce deaths of scavenging species from eating poisoned carcasses (Annex 2, case study 9).

The two types of offset are not mutually exclusive. In many cases, a project may implement offsets that combine both types. For example, a wind farm that has residual impacts on a threatened raptor may offset these through a combination of protection and habitat enhancement measures for the species' breeding habitat elsewhere (Box 16).

Box 16 Key Biodiversity Areas (KBAs) as targets for offsetting

Key Biodiversity Areas (KBAs) are conservation priorities, and unprotected or poorly protected KBAs may be suitable targets for offsets.

IUCN's guidelines on business and KBAs[458] note that KBAs could provide opportunities for 'trading up' offsets, which target different, higher-priority biodiversity features than those impacted. The acceptability of 'trading up' offsets depends on stakeholder values and preferences. They are more likely to be acceptable when the impacted features are of relatively low conservation significance.

Assessing biodiversity losses and gains for 'trading up' offsets can pose some technical challenges, because the biodiversity features are different for impact and offset. Regulators and some stakeholders may also be unwilling to accept 'trading up' offsets when these are distant from the project site, and/or in another country or jurisdiction.

The World Database of Key Biodiversity Areas (Birdlife International) can provide information on KBAs that could be potential targets for offsets, providing a similar or more significant contribution to the global persistence of biodiversity elements than the area impacted by a development.

458 The KBA Partnership (2018).

Box 17 Offset conditions and principles

To help ensure that offsets lead to genuinely positive conservation outcomes that account for both biodiversity and people, the IUCN has identified specific conditions for when offsets are appropriate:[459]

- Offsets must only occur after all previous steps in the mitigation hierarchy have been considered and no alternatives are available. Biodiversity offsets must never be used to circumvent responsibilities to avoid and minimise damage to biodiversity, or to justify projects that would otherwise not happen;
- The mitigation hierarchy must be applied at the landscape or seascape level with mitigation actions designed and implemented at a site or project level. Governments should ensure the mitigation hierarchy is embedded in the framework of landscape and seascape level planning and legislation and is part of existing and future strategic development plans;
- Societal values should also be accounted for and used to inform the design and implementation of biodiversity offsets;
- In certain circumstances, residual impacts on biodiversity (after rigorous application of the mitigation hierarchy) are not offsettable, for example, where the risks are too high or it is not possible to achieve sufficient gains for the target species or ecosystem elsewhere; Box 15). Under these circumstances, biodiversity offsets are not appropriate, and this means the project as designed should not proceed.

There are widely recognised best practice offset principles that will facilitate appropriate offset application for developers. The following need to be carefully considered when planning, designing and implementing biodiversity offsets:

- Equivalence: is an offset a fair exchange for what is lost, either biodiversity that is ecologically similar or different but recognised by stakeholders as being of higher conservation value (referred to as 'trading up')? (Box 14)
- Additionality: will the offset lead to real biodiversity outcomes on the ground, which would not have resulted if not for the offset intervention?
- Long-term outcomes: is the offset designed, implemented and monitored to achieve clear, time-bound and measurable outcomes for biodiversity?
- Longevity: will an offset last at least as long as a project's impacts (sometimes referred to as 'permanence')?
- Stakeholder engagement: have the appropriate stakeholders been engaged in planning and design of the offset, and will they continue to be engaged in its implementation?

7.2 Proactive conservation actions

Solar and wind farms developments can provide positive and meaningful contributions to wider conservation goals and demonstrate good environmental stewardship through the conservation and rehabilitation of local biodiversity. Such initiatives are often referred to as proactive conservation actions (PCAs).

PCAs can encompass a wide range of activities, including conservation-related research, education and awareness-raising that is not necessarily targeted towards addressing project impacts (Annex 2, case study 5). Unlike offsets, PCAs are not designed to deliver measurable gains towards no net loss/net gain targets. Nonetheless, PCAs can facilitate the

459 IUCN (2016).

successful long-term effectiveness of offsets. For example, restoration and protection of a KBA may also require local community understanding and support to be effective in the long term (Annex 2, case study 18).

PCAs can provide businesses with an opportunity to demonstrate good environmental stewardship and contribute towards wider conservation goals (Box 15 and Annex 2, case study 12). For example, wildflower meadows have been created at some solar PV sites to encourage recovery of insect populations, helping to restore both local biodiversity and ecosystem services (Annex 2, case studies 21 and 22). Such biodiversity and ecosystem services considerations need to be integrated into the design, as part of early project planning.

Box 18 Proactive Conservation Actions: The case of Greater Kromme Stewardship, South Africa

The Greater Kromme Stewardship initiative is a conservation project near St Francis Bay in the Eastern Cape, South Africa. The area is home to many threatened species and ecosystems, some found nowhere else. Concerns from local environmentalists about the impacts of wind farms to the area's biodiversity led to the formation of a partnership between the Kromme Enviro-Trust and the wind farms. Five wind farms in the Greater Kromme area have come together to help contribute to positive conservation interventions to the local environment by creating safe havens for vulnerable species and habitats. Their support has led to the formal declaration of small nature reserves that help secure biodiversity on private land. Funding is also used to support entrepreneurs in sustainable green businesses and improve local people's understanding of why it is important to conserve biodiversity.

7.2.1. Opportunities for habitat enhancement

Renewable energy projects have the opportunity to enhance the condition of habitat and associated biodiversity, and deliver positive biodiversity outcomes within the project area, particularly when developed on previously degraded areas such as agricultural land. In the UK, for example solar projects on agricultural or other brownfield sites have been found to enhance the diversity of birds, plants and invertebrates.[460] Well-managed sites can also act as a refuge for some species from the surrounding homogenous agricultural landscape (Annex 2, case study 22).

Offshore wind farm developments can play a role in enhancing seabed habitat and restoring previously degraded ecosystems. For example, in the North Sea, offshore wind farms have been designed to provide artificial reef habitat and support restoration of flat oyster beds (Annex 2, case studies 16 and 17).[461]

On-site habitat enhancement can also provide benefits to the project itself through nature-based solutions to technical issues. For example, revegetation with naturally occurring species within solar developments can enhance biodiversity as well as control dust, thereby reducing the need to use water to clean solar panels,[462] whilst the creation of reef substrate on offshore wind farm foundations can enhance biodiversity whilst reducing the negative effects of scouring.[463]

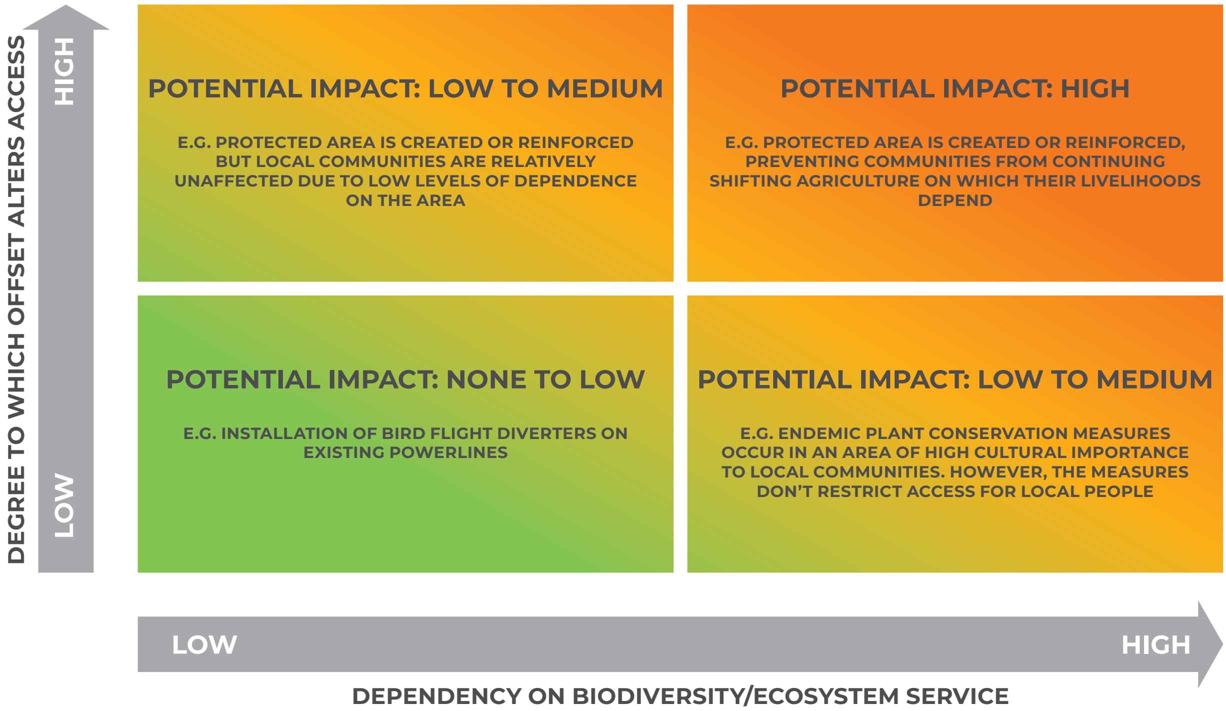
460 Montag et al. (2016). Other key references: BSG Ecology (2014); Beatty et al. (2017); Harrison et al. (2016); Hernandez et al. (2014); Jenkins et al. (2015); Visser et al. (2019).

461 Kamermans et al. (2018); Vrooman et al. (2018).

462 Beatty et al. (2017); Macknick et al. (2013).

463 Lengkeek et al. (2017); Wilson & Elliott (2009).

Figure 7.1 Schematic diagram of potential social impacts of offsets



Note: The potential impacts depend on the interaction between peoples' dependency on ecosystem services and the offset actions. These criteria can be used in early screening to assess the level of risk of different offset options and inform the feasibility and design stage.

Source: Adapted from TBC (2018b, fig. 1, p. 3) and Jones et al. (2019, fig. 3, p. 4).

7.3 Considering impacts of offsets on people

Biodiversity offsets often involve working with people who live in and around the offset area, and who depend on or value ecosystem services from the landscape. Well-planned offsets can enhance delivery of ecosystem services to local people while delivering biodiversity objectives. However, poorly-planned offsets may restrict resource access or negatively impact delivery of ecosystem services.[464] In turn, this can affect the well-being of vulnerable people and lead to conflict. When planning a biodiversity offset, it is important to take into consideration the Rights-based Approaches to conservation (RBA), which focus on the integration of rights, norms, standards, and principles into policy, planning, implementation, and outcomes assessment to help ensure that conservation practice respect rights in all cases, and supports their further realisation where possible.[465]

Consideration of the social context early in offset development can help avoid issues that could undermine a project's social and environmental objectives (Figure 7.1).[466] Offset interventions in areas with few people and low natural resource dependency, such as through enhanced protection of remote seabird colonies, are unlikely to carry significant social risks. Similarly, some species-targeted interventions, such as installing bird flight diverters on existing powerlines to avert collisions, are unlikely to impact people.

In areas of high natural resource dependency, close collaboration with local people is essential to successful offset design and implementation. Delivering positive social outcomes from biodiversity offsets is also increasingly seen as an important objective in itself. Where offsets account for the

464 Bidaud et al. (2018).
465 Campese et al. (2009).
466 Jones et al. (2019); TBC (2018c).

dependencies and needs of local people, they can present opportunities for sustainable positive outcomes for both people and biodiversity. Examples include protection of important fish spawning grounds to provide sustainable local fisheries and wildflower meadow restoration to bring back crop pollinating services provided by insects.

In the same way as on-site mitigation planning, effective offset design requires close coordination between social and biodiversity experts to understand local resource dependencies, identify constraints and develop an appropriate strategy for delivery.[467] Therefore, offset planning should be treated as an integral part of project planning and subject to the same good practice standards as any other component of the project. Offsets will have a higher chance of success if their feasibility assessment (Section 9) and design are carried out with the participation of local communities alongside relevant government bodies and development and conservation partners likely to play a role in the implementation.

Early involvement of this broad range of stakeholders can help form partnerships, build positive relationships and identify potential positive outcomes opportunities for more effective interventions (Section 3.6 on working with stakeholders).

7.4 Practical approaches to offsetting and proactive conservation actions

Designing and planning for offsets takes time and often carries a high level of uncertainty with a real risk of failure. For this reason, scoping offsets to determine 'in principle' feasibility should take place early in the project planning phase, following initial risk screening. This will inform potential development decisions, including the need for further on-site mitigation to reduce or eliminate the need for offsets that are unfeasible, risky or do not meet good practice principles (Table 7-1). In order to avoid significant time lags between project impacts and offset gains, feasible offset approaches should be implemented prior to or during construction.

Specialist advisors and regulatory personnel can help businesses identify, design and develop appropriate offsets that align with national requirements and meet good practice principles to help a project achieve its no net loss/net gain targets.

Table 7-2 gives examples of offset approaches for wind and solar. Many other interventions may be possible, depending on context and the species or ecosystems impacted – offset design gives scope for creativity, providing the offset actions are feasible and effective. Offsets aimed at protecting threatened and/or degraded areas would ideally contribute to national or international conservation priorities. Examples of potentially suitable offset sites include those already identified as national conservation priorities (e.g. the National Biodiversity Strategy and Action Plans (NBSAPs) or international conservation priorities, particularly World Heritage Sites, Ramsar Sites and Key Biodiversity Areas, including BirdLife International's Important Bird and Biodiversity Areas). Offsets may also operate at a broader scale or at policy level rather than being strictly site-based (e.g. anti-poisoning programmes or powerline retrofitting to reduce bird of prey mortality, or improved regulation and enforcement to reduce seabird or cetacean bycatch in fisheries; see Table 7-1). In all cases, the offset will need to meet the offset principles (Box 17) to be acceptable, including that it is *additional* (i.e. would not have happened without the offset) and *comparable* (presents a fair exchange for the biodiversity lost). Additionality is a particular concern where offsets aim to help improve protection and management of existing but under-resourced protected areas (Annex 2, case study 18). In such cases, it needs to be clear that offset funding is not replacing other potential conservation investment or enabling cost-shifting by governments.

467 See Bull et al. (2018) for further guidance and good practice principles on ensuring no net loss for people. This guidance provides a framework for defining measurable social outcomes and assessing whether the social considerations of biodiversity no net loss measures have been sufficiently accounted for.

Table 7-1 Key considerations and outputs during each phase of offset planning

Offset development phase	Project development phase	Objectives	Outcomes
Offset scoping, screening and pre-feasibility assessment	Early planning	Identify significant residual impacts to priority biodiversity Forecast (either quantitative or qualitatively) the magnitude of residual impacts to priority biodiversity Narrow down offset options based on their feasibility, including: **Theoretical:** are there threats elsewhere to similar biodiversity that can be tackled; are there habitats that can be restored? can delivery of ecosystem services be maintained or can people be compensated for impacts to their livelihoods? **Technical:** are there successful approaches that could be applied to achieve sufficient gains within the required timescale, and within a realistic cost? **Socio-political:** is there sufficient government and societal support for the proposed intervention? are there existing governance and finance mechanisms that can facilitate offset implementation?	Assessment of residual impacts to priority biodiversity Shortlist of candidate offset sites and actions
Offset design & feasibility assessment	Project design	Identify appropriate conservation interventions that can be supported through offsets Undertake detailed feasibility assessment, including engagement with government and community stakeholders Develop partnerships for offset implementation and monitoring Identify appropriate indicators and management response thresholds to monitor losses and gains and adaptively manage progress towards no net loss/net gain objectives Establish offset governance structure with representation from project and key stakeholders or implementation partners Identify appropriate long-term financing mechanism	Offset management plan including detailed offset actions Forecast of gains that can be achieved through offset actions Biodiversity indicators and thresholds for measuring progress Formal governance & financing agreement
Offset implementation	Construction and operations	Implement offset plan with partners Undertake monitoring and reporting to demonstrate progress towards no net loss/net gain	Monitoring and evaluation reports, including adaptive management in response to monitoring information

Note: Where they exist, national regulatory offset frameworks may have different or additional requirements.

Source: Adapted from (CSBI (2013, p. 6).

Table 7-2 Examples of offset approaches for solar and onshore and offshore wind projects

Offset type	Solar	Wind – onshore	Wind – offshore
Restoration	Restore degraded areas of similar habitat	Improve condition of preferred raptor habitat Captive breeding and successful reintroduction of raptor species where populations are depleted	Protect and restore prey species stocks Eradicate invasive species from nesting grounds of seabird species Improve condition of foraging or breeding grounds for marine mammals
Avoided loss	Protect a threatened area of similar habitat off-site	Retrofit non-project power lines to prevent bird electrocution or collisions Protect roosts at risk elsewhere for priority bat species Reduce predator-livestock conflict to prevent incidental poisoning of scavenging bird species Protect key stopover, passage, nesting or wintering sites for migratory birds Support awareness, enforcement and alternative livelihoods programmes to reduce illegal capture/hunting of migratory bird species	Protect nesting grounds for migratory birds in their breeding areas (off-site) Support implementation of locally-managed marine areas to protect priority species or habitat Support prevention of fisheries bycatch for priority species

Note: Offsets will be targeted at priority habitats or species, to compensate for residual impacts of the project.

Aggregated offsets

Where multiple wind or solar farms are impacting similar biodiversity, developers may wish to pool their resources into a joint intervention, called an aggregated offset. This can help address cumulative impacts to particular species or ecosystems. Aggregated offsets have the benefit of spreading risks and costs across several developers, as well as reducing overall transaction cost and potentially improving efficiency and effectiveness. They do, however, require close collaboration between developers to agree to a fair proportion of financing, based on the specific offsetting requirements of each project, and the offset's governance and implementation arrangements.

Aggregated offsets are particularly relevant to wind and solar projects as multiple developments are often located in areas of high renewable energy potential and thus have similar impacts and offsetting requirements. For example, several wind farms could pool resources to invest in protecting a key nesting site for a priority bird species, as a means to offset the cumulative impact of turbine collisions within the wider landscape. Through an aggregated approach, developers can more effectively meet no net loss/net gain targets while also aligning with national strategies and contributing to wider conservation planning.

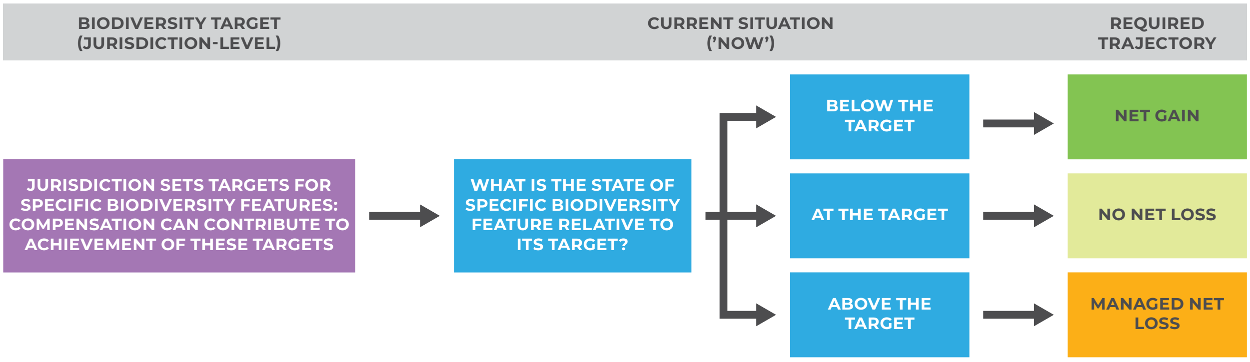
Experience with aggregated offsets is limited so far, but they are likely to become increasingly popular as countries develop national regulatory schemes that require developers to contribute to specific quantitative conservation targets (Section 8).

Offsets within national legislative frameworks

Offsets can be easier and more straightforward to plan and implement where they sit within existing regulatory offset frameworks. These include market-based mechanisms that allow the purchase of 'off the shelf' biodiversity credits through a habitat or conservation bank. Conservation banks also help address some of the uncertainty around offset success by producing gains in advance, before development impacts. However, they have not been implemented widely and so are unlikely to be available for many taxa impacted by renewable projects such as birds and bats.

The post-2020 strategic framework of the Convention on Biological Diversity (CBD)[468] is expected to include updated goals and targets for biodiversity. CBD parties may use these to develop explicit national biodiversity conservation targets, which in turn can be used to scale requirements for compensation of project impacts. This approach enables offsets to move beyond project-specific no net loss/net gain goals and contribute explicitly to jurisdictional targets. Offset requirements would then be determined based on the current state of biodiversity being adversely impacted by the development (Figure 7.2). Such targets can be considered within wider strategic level planning exercises (Section 3.2 on SEAs), providing an integrated approach to conservation planning and a clear and transparent basis for compensation from development. While national targets would scale the requirements for compensation, the principles for good practice offset design and implementation should remain unchanged.

Figure 7.2 Identification of an appropriate, jurisdiction-level target for biodiversity



Note: The required trajectory depends on whether a biodiversity feature is below, at or above its current target.
Source: Simmonds et al. (2019, fig. 2, p. 5).

468 Currently under negotiation.

8. Assessment, monitoring and evaluation

8.1 Surveys for risk, impact assessment and monitoring

Effective mitigation of project impacts requires a comprehensive understanding of biodiversity features present in the area and their likely direct and indirect interactions with project operations. Biodiversity surveys allow developers to evaluate risks and impacts associated with a project and help design and implement mitigation actions. Information derived from ongoing surveys can be used to evaluate the effectiveness of mitigation actions and inform adaptive management to ensure the project stays on track to meet its biodiversity objectives.

Early scoping of survey objectives focused around project risks will help ensure they are fit for purpose and make efficient use of project resources. In most cases, consultation with specialists and stakeholders familiar with the wider project area and its biodiversity is needed to inform field surveys. The specific scope and objectives will depend on the survey type. Projects frequently conduct three types of biodiversity surveys (Figure 8.1):

- **Risk surveys** help identify biodiversity features at risk from project impacts, as identified through early project screening. They are broad in scope and aim to confirm the presence and distribution of biodiversity within the project's wider area of influence, also accounting for associated project infrastructure such as transmission lines and roads. They are undertaken during early project planning to assess risks but also to enable identification of early avoidance opportunities. In some cases, surveys will need to target sensitive sites far removed from the actual project site, such as seabird nesting colonies, whose foraging range overlaps with the project.
- **Impact and mitigation surveys** are undertaken during project design and are focused on priority biodiversity features at risk of impact. They support the assessment of impacts and help identify appropriate mitigation responses as part of the ESIA process. These surveys can also provide data to forecast residual impacts and inform offset requirements. Multiple rounds of surveys across one or more years may be needed to develop an understanding of a species' ecological requirements, population and seasonal distribution (i.e. due to wet and dry season variations and/or migration patterns). Like risk surveys, the geographic scope needs to consider the project's wider area of influence.
- **Monitoring baseline surveys** are undertaken to provide a baseline of the biodiversity status, prior to impacts occurring. Monitoring surveys allows assessment of progress against project goals and any relevant regulations, policies or lender requirements. The surveys are designed to be repeatable so that the effectiveness of mitigation actions can be tracked over the project's lifetime through comparisons with the monitoring baseline. Control sites outside of the project's influence may also be needed to be able to distinguish project impacts from background changes and natural variability.[469]

Information from monitoring surveys can also be used to inform avoidance and minimisation as part of repowering, to identify turbines or solar panels that disproportionally contribute to species fatalities and decommissioning these.

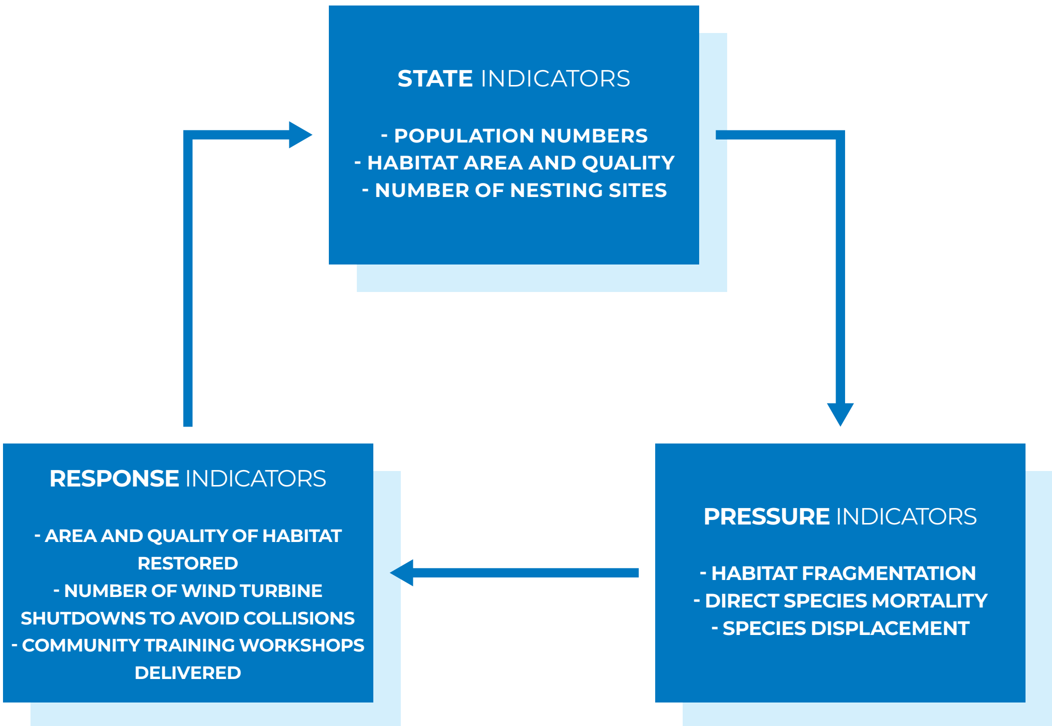
469 An internationally established approach is the Before-After-Control-Intervention (BACI), which can help provide a robust method for quantifying impacts and improve understanding of biodiversity impacts. For example, see Sansom et al. (2016).

Figure 8.1 Survey types through the project development cycle (top row), including an example of an approach for a threatened bird species at risk from wind farm impacts (bottom row)

EARLY PLANNING	PROJECT DESIGN		CONSTRUCTION	OPERATIONS	CLOSURE & DECOMMISSIONING	REPOWERING
RISK SURVEYS	IMPACT & MITIGATION SURVEYS	MONITORING BASELINE	MONITORING SURVEYS			
- IDENTIFIES BIODIVERSITY AT RISK OF PROJECT IMPACT	- ENABLES IMPACT ASSESSMENT AND QUANTIFICATION - SUPPORTS DEVELOPMENT OF MITIGATION MEASURES	- PROVIDES A BASELINE TO TRACK EFFECTIVENESS OF MITIGATION MEASURES	- TRACKS EFFECTIVENESS OF MITIGATION MEASURES - TRACKS PROGRESS TOWARDS BIODIVERSITY GOALS			
Confirm presence and broad distribution including seasonal activity in the wider project study area	Target effort to identify species movements and congregations (nesting, roosting) and estimate population numbers in wider area	Establish pre-project population numbers, flight patterns and threats at project (impact) site and reference site(s)	Undertake ongoing (seasonal) surveys at project and reference sites to quantify impacts and effectiveness of mitigation measures such as shutdown on demand. For establishing bird mortality from turbine collisions, this needs to include searcher efficiency trials & scavenger removal rates, carcass searches and estimates of collision rates			

Appropriate monitoring indicators from which to track impacts should include measurements of both the state of project biodiversity as well as project pressure (impacts) and mitigation responses, including offset gains (Figure 8.2). Biodiversity indicators often focus on habitat as a useful proxy for biodiversity, for example, through the use of measures of both habitat extent and condition (Annex 2, case study 19). Indicators will also need to enable adaptive management, based on appropriate quantitative thresholds that trigger a response for additional mitigation action.

Figure 8.2 Appropriate indicators to track impacts



Note: Indicators should include measurements of both the state of project biodiversity as well as project pressure (impacts) and mitigation responses.

8.2 Approaches to good practice monitoring

This section presents approaches to help provide developers with the information needed to guide effective risk management and align with stakeholder expectations. Specific monitoring needs will vary depending on regulatory requirements, company standards or lender safeguards (Section 9). Additional guidelines on good practice monitoring are presented in Annex 1.

Ensure level of effort is commensurate to risk

The level of monitoring effort should be commensurate with the risks associated with a development, based on the priority biodiversity values present and the scale and magnitude of impacts. Where biodiversity risks are low, it may be possible to combine survey events, for example, if high-risk sites are avoided through prior strategic planning. and/or careful screening, projects may be able to combine risk and impact/mitigation surveys instead of conducting these separately. Long, multi-year pre-construction surveys can sometimes be avoided, if developers commit to comprehensive monitoring throughout project construction and early operational phases to be able to respond to any significant and/or unforeseen risks through ongoing observer-led shut-down on demand for high-risk wind farms.

Coordinate survey effort between developers

Project-level monitoring provides valuable contributions to the emerging understanding of biodiversity interactions with renewable energy developments that is relevant to decision-making at a much larger scale. Where possible, monitoring approaches should be standardised across projects and regions to facilitate the direct comparison and analysis of results from multiple projects. The IUCN Species Monitoring Specialist Group can play an important role in facilitating and coordinating this process, supported by international NGOs and academic institutions.

Coordination of survey effort across multiple projects can also save costs by avoiding duplication of effort and through efficiencies of scale. Such coordinated efforts can help develop a broader understanding of project impacts and identify more effective mitigation strategies that account for cumulative impacts. Such a regional approach has been recommended for fatality estimation in southern Australia.[470] Increasingly, jurisdictions, including Canada, South Africa and the USA,[471] are developing national technical guidelines, which help ensure monitoring efforts are aligned across renewable energy developments.

Share project biodiversity data wherever possible

Data sharing and transparency can help developers maintain their social license to operate by demonstrating a commitment to good mitigation practice and contributing to wider conservation efforts. In turn, this information can help regulators assess cumulative impacts and support strategic landscape/seascape-level planning. For example, the Wolfe Island Wind Farm in Ontario, Canada[472] and the Gullen Range Wind Farm in New South Wales, Australia have both made monitoring information available to support wider impact assessment and conservation planning. Similarly, the Belgian government makes monitoring data from all offshore wind farms available to support coordinated approach to assess and help address cumulative impacts.[473] Wherever possible, businesses are also encouraged to make their data available through

470 Moloney et al. (2019).

471 Aronson et al. (2014); Jenkins et al. (2015); New York State Department of Environmental Conservation (2016); Saskatchewan Ministry of Environment (2018).

472 TransAlta (2014).

473 Royal Belgium Institute of Natural Sciences (n.d.).

global biodiversity databases such as the Global Biodiversity Information Facility (GBIF).[474] This is also seen as good practice by a growing number of financial institutions.[475]

8.3 Specific monitoring and study needs

Monitoring species displacement

Monitoring to detect displacement of species as a result of the project is challenging and requires a robust baseline dataset as well as information from adjacent control sites to provide a comparison environment. For both birds and bats at risk of collision at wind farms, some level of displacement is implicit in collision risk models – i.e. if individuals regularly avoid areas with turbines, then they will be displaced from those areas. The magnitude of this effect will likely to be different for different species, locations and turbine layouts. Species that do not fly and are not at risk of collision may also avoid wind turbines and associated infrastructure and may need to be accounted for separately. For solar projects, species may be displaced from a greater area, but this is rarely significant in the context of their regional or global distribution. Usually, the loss or abandonment of breeding or roosting sites is of greater concern, and monitoring should therefore focus on these sites. Monitoring should commence as early as possible in the project cycle to establish a robust pre-construction baseline, ideally three or more years prior to construction (although in some cases, projects may be able to benefit from existing data). At a minimum, pre-construction monitoring should include measures of presence (e.g. number of occupied nests in and around the project area) and abundance (e.g. numbers of bats using a roost site, or breeding butterflies within the project area). Other indicators may consider measures of productivity, such as number of individuals fledge per nest (as this may be lower in the project area than at non-impacted sites), or the fate of individuals using known breeding or roosting sites (a bat roost may have the same numbers between years, but if all the individuals present in year one were killed by the project and replaced by individuals from other areas, that might represent significant impact).

Monitoring barrier effects

Barrier effects are predicted to be most strongly observed in response to the cumulative effects of multiple adjacent wind farms. Although monitoring to detect barrier effects can take place at individual wind farms, it is more likely to provide useful information when conducted at a broader scale, covering multiple adjacent developments. Barrier effects can be identified by tracking the movement of individual birds (especially migrants) to see how they respond to multiple wind farms at the landscape scale along their migratory route. Such studies are best coordinated by species-specialist groups (e.g. IUCN Species Specialist Groups). Projects are encouraged to support such large-scale monitoring efforts to determine the existence and magnitude of barrier effects for any species.

Estimating bird and bat fatalities at wind farms

For many wind farms, the major biodiversity risk will be collisions of birds and bats with turbine blades and transmission lines associated with the project. This is not as relevant for solar projects where few direct fatalities are predicted. Traditional fatality estimation is currently not possible for offshore wind, as any carcasses fall into the sea and are unlikely to be found. Offshore wind farms may need to consider alternative technologies, such as vibration sensors and thermal infra-red cameras, to detect and estimate collisions.[476] Projects may need to estimate

474 GBIF is an international network and research infrastructure funded by the world's governments aimed at providing open access to biodiversity data.

475 For example, see Equator Principles Association (2020).

476 Robinson Willmott et al. (2015).

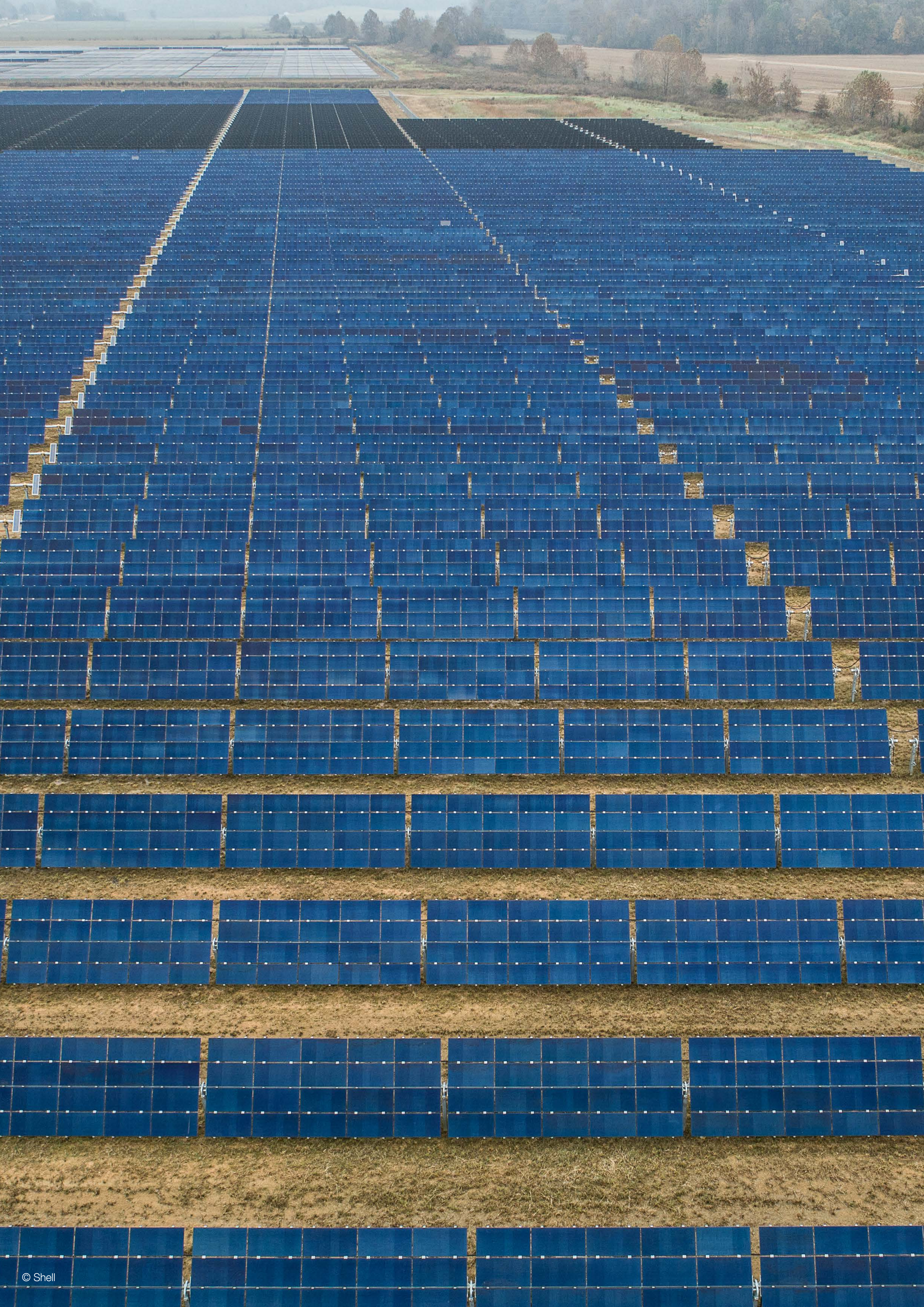
the number of individuals of priority species killed to compare against fatality threshold commitments. Estimating fatalities at an onshore wind farm requires:

- Regular searches under turbines and transmission lines for carcasses;
- Estimation of the carcass persistence rate, as some carcasses will be removed by scavengers before a search is undertaken;
- Estimation of the searcher efficiency, as some carcasses will be missed by searchers, even if present; and
- Estimation of the proportion of carcasses within the search area of each turbine or transmission line.

Fatality monitoring is only required when priority species are present and at risk of collision. For migratory species, this might mean during the migratory season, or during their overwintering period, if they overwinter close to or at the project site.

A variety of methods are available for the estimation of fatalities, with GenEst[477] being the currently recommended approach; however, for species with few (<10) detected fatalities Evidence of Absence[478] may be more valid to use. Both are web-based software packages, and use the fatalities found during searches and the estimated searcher efficiency and carcass persistence information, to estimate the true number of fatalities at the project site. Whatever analysis approach is taken, a detailed understanding of the estimation methods is required to ensure monitoring is fit for purpose.[479] Even with optimal monitoring, the analysis will provide a fatality estimate range. Additional interpretation may be needed to determine the impact of the wind farm.

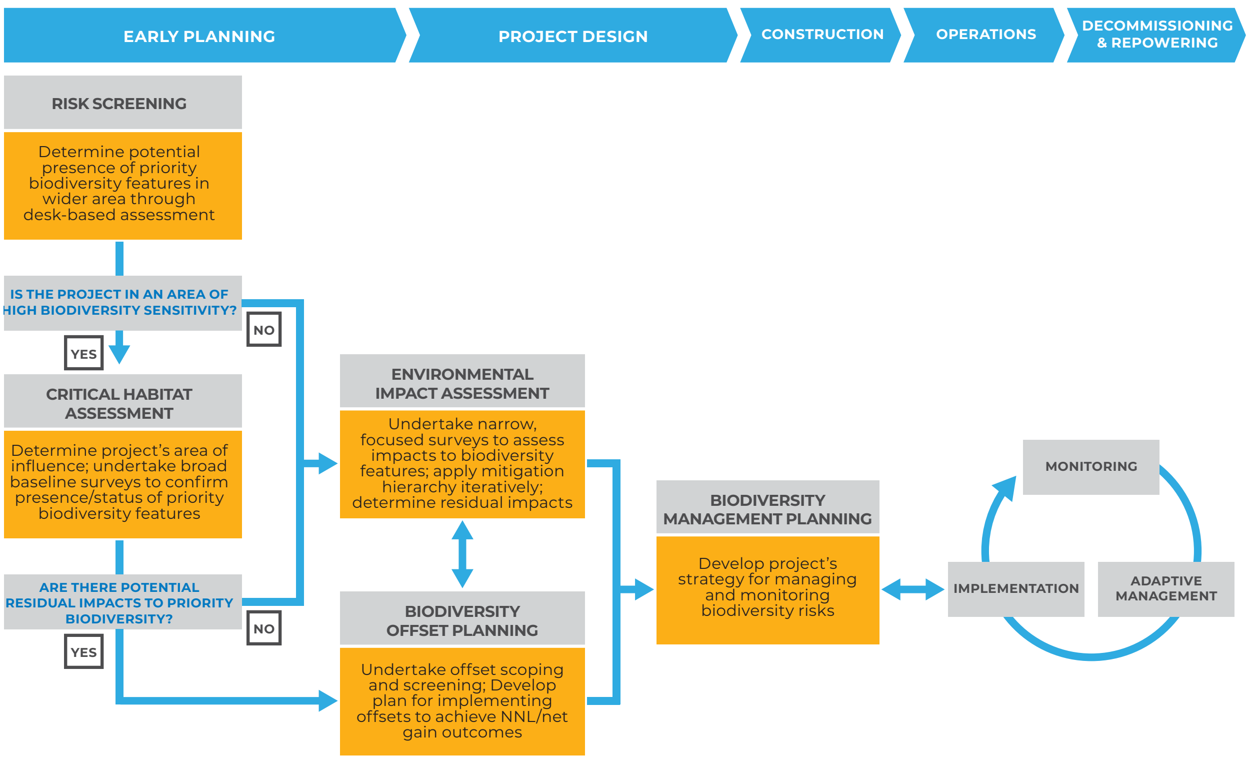
477 Simonis et al. (2018).
478 Dalthorp et al. (2017).
479 For example Moloney et al. (2019).



9. Process for aligning with good practice

Table 9-1 highlights key activities for aligning with good biodiversity management and provides recommended relevant guidelines from across industries. Specific requirements will depend on lender safeguards (e.g. IFC's Performance Standard 6) and national legislative requirements. Projects operating in areas of low biodiversity risk or sites already identified for renewable energy development such as through strategic assessments (Section 3) may not require the same level of mitigation planning and reporting. Early integration of biodiversity-specific assessment into the ESIA can help reduce project risk and align with lender safeguards and legislative requirements, avoiding permitting delays. Such a risk-based approach will also help focus further effort around identifying and mitigating key risks as part of the ESIA process (Figure 9.1).

Figure 9.1 Key project activities and outputs for a good biodiversity practice



Note: Specific requirements depend on the biodiversity risks and potential for significant residual impacts. This diagram does not account for specific legislative requirements which will vary between countries.

Table 9-1 Key project activities and outputs for aligning with good biodiversity practice

Activity	Description and relevance to good biodiversity risk management	Further guidance documents
Strategic Assessment	Analytical and participatory approach that integrates environmental considerations with national policies and plans and evaluates the inter-linkages with economic and social considerations. Helps to identify preferred sites for renewable development within areas of low biodiversity sensitivity and risk. Provides the context and framework for assessing project environmental impact assessments.	Migratory Soaring Birds Project guidelines for solar developments.[480]
Risk screening	Initial desk-based assessment of potential biodiversity risks, alongside mitigation opportunities, including site alternatives and offsets, based on existing information. Informs project feasibility assessment as well as implications for meeting regulatory requirements and financing safeguards.	TBC Industry Briefing Note on early screening.[481] FFI Good Practice Guidance for Oil and Gas in Marine Environments.[482]
Critical Habitat Assessment	Determination of areas of high biodiversity value based on criteria and quantitative/semi-quantitative thresholds (as per IFC PS6). Helps focus ESIA survey and mitigation on key biodiversity risks and targets project no net loss/net gain biodiversity goals.	IFC Performance Standard 6 Guidance Note.[483] TBC Industry Briefing Note on Critical Habitat.[484]
Environmental and Social Impact Assessment	Identification of mitigation measures to avoid/minimise/restore impacts through iterative application of mitigation hierarchy and qualitative assessment of biodiversity impacts. **Residual Impact Assessment**: assessment (either quantitative or qualitative) of residual impacts to priority biodiversity following application of planned mitigation measures; establishes offset targets to achieve no net loss/net gain. It can also promote further mitigation (avoidance and minimisation) to reduce offset liabilities. **Cumulative Impact Assessment (CIA)**: identifies potential biodiversity impacts and risks of multiple existing and proposed developments and identifies appropriate measures to mitigate such cumulative impacts and risks. A CIA is especially warranted when multiple wind and/or solar developments are sited in close proximity to sensitive biodiversity features. Cumulative impacts are ideally addressed through a strategic assessment (see above).	CSBI Cross-sector Guide to Implementing the Mitigation Hierarchy.[485] FFI Good Practice Guidance for Oil and Gas in Marine Environments.[486] ICMM Good Practice Guidance for Mining and Biodiversity.[487] IFC Cumulative Impact Assessment and Management: Guidance for the Private Sector in Emerging Markets.[488] SNH Assessing the cumulative impacts of onshore wind energy developments.[489]

480 BirdLife International (2015).
481 TBC (2017).
482 FFI (2017).
483 IFC (2019).
484 TBC (2012).
485 TBC (2015).
486 FFI (2017).
487 ICMM (2006).
488 IFC (2013).
489 SNH (2012).

Biodiversity management planning	**Biodiversity Action Plan (BAP)**: overarching framework for managing biodiversity risk through identification of priority receptors and appropriate management actions. Includes a concrete set of planned, measurable, actions to mitigate (and offset) biodiversity impacts and achieve no net loss/net gain goals. A BAP is an IFC requirement under PS6 for projects operating in Critical Habitat. **Monitoring and Evaluation Plan**: provides details of specific planned monitoring actions, including associated indicators for tracking impacts and mitigation measures, and thresholds for undertaking adaptive management actions. Validates the accuracy of predicted impacts and risks and helps to demonstrate to stakeholders that mitigation measures are effective and the project is on track to achieve its biodiversity goals.	FFI Good Practice Guidance for Oil and Gas in Marine Environments.[490] Good Practices for the Collection of Biodiversity Baseline Data.[491] IPIECA Guide to Developing Biodiversity Action Plans for the oil and gas sector.[492] TBC Industry Briefing Note on How to make biodiversity surveys relevant to your project.[493]
Biodiversity offset planning	**Offset Strategy**: overarching approach for implementing offsets based on scoping and screening of offset options. Includes an evaluation of the technical and political feasibility of implementing offsets and forecasting of gains that demonstrates the achievability of achieving no net loss/net gains. It establishes the feasibility (and potential costs) of offset options and identifies offset risks and uncertainty. **Offset Implementation and monitoring Plan**: a detailed plan for implementing offsets, including oversight, financing mechanism and partnerships. Helps the project and stakeholders track the offset effectiveness and adaptively manage the offset to ensure it delivers on its biodiversity goals.	BBOP Biodiversity Offset Design Handbook.[494] TBC Industry Briefing Note on biodiversity offsets.[495]

490 FFI (2017).
491 Gullison et al. (2015).
492 IPIECA & OCP (2005).
493 TBC (2018b).
494 BBOP (2012).
495 TBC (2016).

10. Supply chain stewardship

10.1 Overview

The increase in renewable energy development will also see an increased demand for the materials that make these technologies possible. These include materials needed for the construction and storage of wind and solar technologies, such as neodymium for permanent magnets in wind turbines, silver for solar cells and cobalt and lithium for storage batteries.

Mining of materials needed for renewable energy development can themselves have significant biodiversity impacts where they are mined in sensitive areas (Table 10-1). Without strategic planning, these new threats to biodiversity risk surpassing those averted by climate change mitigation.[496] Typical impacts include direct habitat loss and degradation from the mining footprint and associated infrastructure and indirect impacts associated with induced in-migration into previously inaccessible areas.[497] For example, the increasing demand for cobalt is likely to require an expansion of mining in the Democratic Republic of the Congo, the world's largest supplier of cobalt and a country supporting one of the world's largest remaining intact forests.[498] While deep-sea mining offers opportunities to source materials needed for renewable energy development from the seafloor, the industry is not yet well developed and carries environmental risks that need to be carefully considered.

One way for developers to source their materials more responsibly is by purchasing them from companies that meet industry standards and have relevant accreditation. A number of certification schemes exist that aim to provide developers with assurance that the minerals they buy are mined responsibly. These include:[499]

- The Aluminium Stewardship Initiative (ASI) which sets standards and provides third-party certification across the production and supply chain;
- The Initiative for Responsible Mining Assurance (IRMA), which provides third-party certification of industrial-scale mine sites;
- The Responsible Minerals Initiative (RMI) which undertakes assessment and auditing to validate conformance with its standards. Responsible Steel which is developing a global standard and certification scheme for the industry; and
- The Towards Sustainable Mining Guiding Principles developed by The Mining Association of Canada, which describes a set of protocols and frameworks for measuring and demonstrating industry performance in key environmental and social aspects.

10.2 Renewable energy as part of the circular economy

Renewable energy development is recognised as a fundamental part of the transition from a linear economic model, which relies on large quantities of easily accessible and non-renewable resources and

496 Sonter et al. (2020).
497 Ibid. (2018).
498 U.S. Geological Survey (2019).
499 There are currently no certification schemes or standards available specific to deep-sea mining.

energy, towards a circular economy that maximises the re-use of existing resources within increasing environmental constraints. Optimising the reuse of materials is an important strategy within the renewable sector to reduce the need for raw materials and the environmental impacts associated with sourcing of these materials (Box 19). Repowering offers opportunities to recover and remanufacture these materials to develop new wind turbines or solar plants whilst minimising the need for new materials (Figure 10.1).

The vast majority of materials used in the manufacture of wind and solar facilities are comprised of substances, which can be recycled during site decommissioning and repowering. For example, wind turbines have a recyclability rate of ~90% if all materials are recovered, although turbine blades still pose a challenge in terms of recyclability due to their complexity.[500,501] Note, however, that certain materials, such as copper, lithium, silver and rare earth metals needed to manufacture magnets (such as dysprosium and neodymium), present practical and technological challenges for recycling. Procurement of these materials should ensure they are sustainably sourced.[502]

Table 10-1 Relative biodiversity risk associated with sourcing of materials needed for wind and solar development

Material	Solar	Wind	Risk to biodiversity and associated ecosystem services*
Aluminium	Frame	Tower	High
Cadmium	Solar cells		Medium
Carbon fibre, fibreglass		Blades	Medium
Cement	Foundations, buildings	Foundations, buildings, tower	Medium
Cobalt	Battery	Battery	High
Copper	Associated components	Generator	High
Dysprosium and Gallium (as a by-product of mining other metals, notably aluminium and copper)	Solar cells	Magnets	High
Graphite	Battery	Battery	High
Indium (as a by-product of zinc mining)	Solar cells		High
Lithium	Battery	Battery	Medium
Neodymium		Magnets	High
Selenium (as a by-product of copper mining)	Solar cells		
Silver	Solar cells		High
Steel (iron ore)		Tower	High
Tellurium (as a by-product of copper and iron mining)	Solar cells		High

** Based on where it is typically sourced from.*

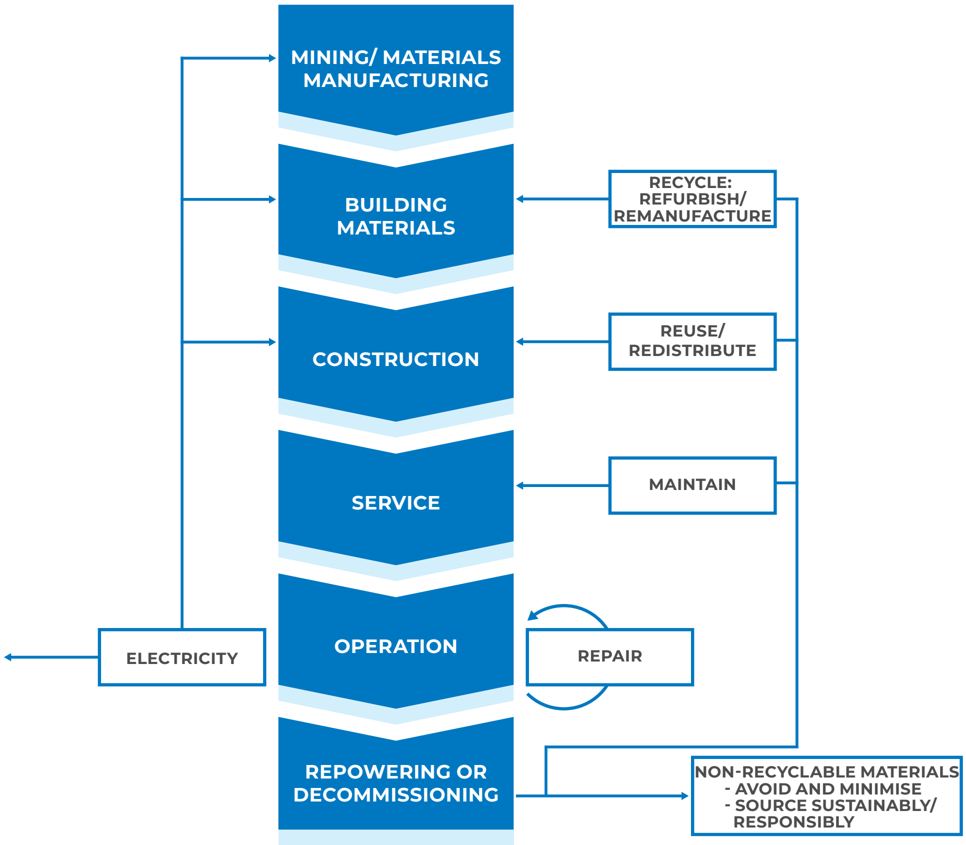
Note: High biodiversity risk includes materials that are predominantly sourced from areas of high biodiversity sensitivity (e.g. Democratic Republic of the Congo) and where the extraction process is likely to have significant direct and indirect impacts to biodiversity.

500 European Technology and Innovation Platform on Wind Energy; Sánchez et al. (2014).

501 Welstead et al. (2013).

502 Dominish et al. (2019).

Figure 10.1 Renewable energy as part of the circular economy



Box 19 Life cycle assessment

A life cycle assessment (LCA) allows developers to account for their environmental impacts across all the stages of a project's lifespan, including raw material extraction through to processing, manufacture, operations, and repowering or decommissioning.

Since 1999, Vestas has been developing LCAs for their wind power projects to provide a 'cradle to grave' evaluation of the environmental impacts of its products and activities. These concentrate on two key actions:

1. Document the environmental performance of wind turbines
2. Analyse the results to improve or develop wind turbines with less environmental impact

The studies assess a wind turbine's entire bill-of-materials accounting for the approximately 25,000 parts that make up a wind turbine. In an LCA, a complete wind power plant is assessed up to the point of the electricity grid, including the wind turbine itself, foundation, site cabling and the transformer station.

Similarly, Siemens Gamesa calculates the environmental footprint of their wind turbines by conducting LCAs. This includes a cradle-to-grave assessment which considers the sourcing of materials, manufacturing of the main parts, installation, operation and maintenance, dismantling, recycling, and end-of-life disposal.[503]

503 https://www.siemensgamesa.com/en-int/-/media/siemensgamesa/downloads/en/sustainability/environment/siemens-gamesa-environmental-product-declaration-epd-sg-8-0-167.pdf

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Annex 1.

Catalogue of resources relevant to mitigating biodiversity impacts associated with solar and wind energy development

To facilitate search and update this catalogue is made available as a separate spreadsheet, available for download alongside the guidance. At the time of publication (February 2021) it contains information on 130 resources including guidance, reviews, technical reports/articles, tools, databases and websites. The catalogue provides summary information on the scope and application of each resource, as well as weblinks.

As well as globally applicable resources, resources with a narrower geographical focus are included where these have broader relevance or as examples of approaches that could be adapted and implemented elsewhere.

To suggest additional resources for the catalogue, including newly published or updated materials, or any corrections, please e-mail the IUCN Business and Biodiversity Programme at biobiz@iucn.org.

Note that IUCN and TBC are not responsible for ensuring the availability of catalogued resources, nor for the validity or security of weblinks included in the catalogue.

Annex 1 is available from the IUCN Library.

Annex 2.

Case studies to support the Guidelines for mitigating biodiversity impacts associated with solar and wind energy development

Case study 1

Marine spatial planning in the Belgian North Sea

Location
North Sea, Belgium

Mitigation hierarchy component
Avoidance by site selection (early planning)

Brief description of the project/initiative
Careful marine spatial planning facilitates the sharing of space among multiple users and activities. Adaptive management and a clear monitoring strategy are vital in such contexts. WindEurope conducted a study for the government of Belgium to assess the feasibility of co-location options for offshore wind farms in the Belgian part of the North Sea, which is highly crowded, with benthic ecosystems heavily degraded due to bottom trawling. It is therefore essential that the co-location of offshore wind farms with marine protected areas, commercial fishing and aquaculture activities, and even other forms of energy generation, such as wave or tidal energy, are carefully considered to support the transition to renewable energy, while preserving biodiversity and ecosystem function.

This work highlighted the importance of pilot tests for co-location options, promoting sustainable aquaculture practices and making use of the positive environmental effects, such as the artificial reef effect, of offshore wind farms.

New concessions are being made for offshore wind farms, which will be partly located inside the Vlaamse Banken Natura 2000 area, a marine protected area recognised for its natural benthic habitats such as reefs. Operational wind farms are suggested to indirectly support the conservation of benthic ecosystems through active measures deployed in combination with aquaculture activities.

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WindEurope (n.d.). *Multiple-uses of offshore wind energy areas in the Belgian North Sea*. Available at: https://windeurope.org/data-and-analysis/product/multiple-uses-of-offshore-wind-areas-in-the-belgian-north-sea/#overview

Offshore wind turbines in North Sea
Photo: © WindEurope

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Case study 2

Avoiding impacts on fauna in the Wadden Sea World Heritage Site

Location
Wadden Sea, Denmark, Germany, Netherlands

Mitigation hierarchy component
Avoidance and minimisation (cable corridors)

Brief description of the project/initiative
The Wadden Sea encompasses the coastal zone from Den Helder in The Netherlands to Blåvands Hulk in Denmark, and is an 'exceptional ecosystem of global importance', according to the 2010 Trilateral Wadden Sea Plan ('the Trilateral Plan', a common policy and management plan for the Wadden Sea area). A trilateral cooperation based on a joint declaration between Denmark, Germany and The Netherlands has enabled the protection of this ecosystem for the past four decades.

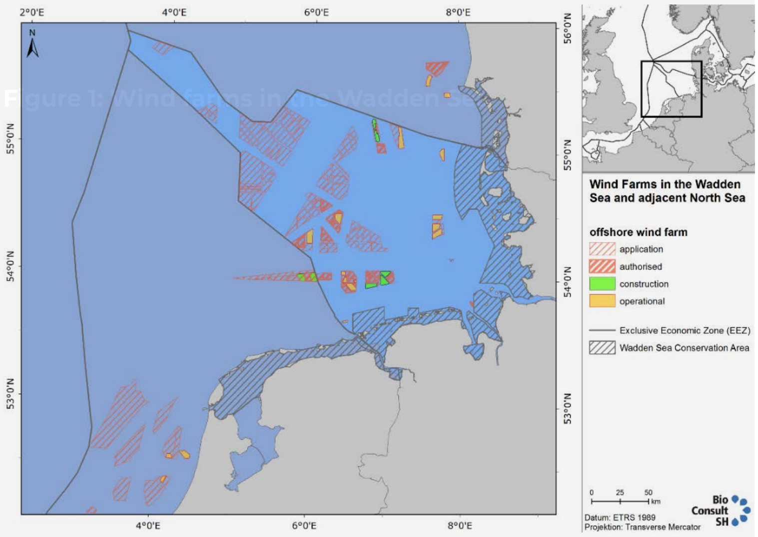
In 2009, the Wadden Sea was inscribed on the World Heritage List for its coastal habitats in Germany and The Netherlands. In 2014, it was extended to add the Danish area. The Wadden Sea represents the largest unbroken system of intertidal sand and mudflats in the world, which attracts a large number of marine mammals and birds. It is an essential stopover that enables the functioning of the East Atlantic and African-Eurasian migratory flyways.

There are multiple offshore wind farms outside the Wadden Sea World Heritage site, at various stages of development (from application-stage to operational) (Figure 1). The Trilateral Plan states that development of wind farms inside the Wadden Sea is prohibited, and that development is only permitted outside the area if important ecological and landscape values are not negatively affected. In addition to marine mammals and birds, the plan identifies several other targets to protect fish, rural area, offshore area, estuaries, beaches and dunes, tidal area, salt marshes, water and sediment, and landscape and culture. The Trilateral Plan also notes that cable corridors should be concentrated to minimise cable crossings through the Wadden Sea.

For further information, please see:
http://whc.unesco.org/en/list/1314/

Reference

Baer, J. and Nehls, G. (2017). 'Energy'. In S. Kloepper et al. (eds.), *Wadden Sea Quality Status Report 2017*. https://qsr.waddensea-worldheritage.org/sites/default/files/pdf_using_mpdf/Wadden%20Sea%20Quality%20Status%20Report%20-%20Energy%20-%202019-07-24.pdf



Source: Baer & Nehls (2017, fig. 5, p. 7).

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Case study 3

Chirotech®, an automated curtailment system for wind power plants

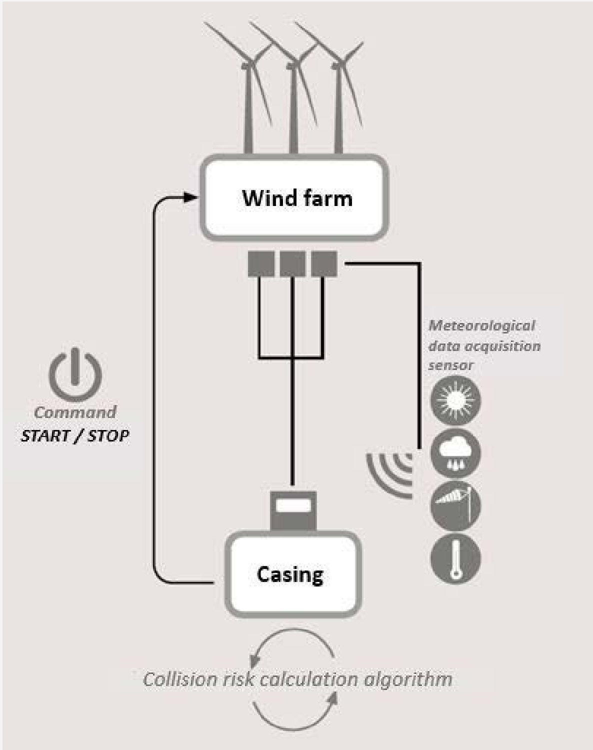
Location
First tested in Boin and Mas-de-Leuze (France), and has since been used by dozens of wind power projects across Europe and in Canada

Mitigation hierarchy component
Minimisation: to reduce wind farm bat fatalities

Brief description of the project/initiative
Chirotech® is an automated system for regulating wind turbines to reduce bat mortality. It is based on the observation that peaks of bat activity at low wind speeds, mostly at dawn and dusk, are generally not when wind turbines are most productive. The system is based on bat behaviour (including flight height) modelled in response to temperature, wind, rainfall and, if possible, from local monitoring data. Using real-time environmental data, Chirotech® determines if a collision risk threshold is exceeded, and then automatically stops the turbines.

Chirotech ® was developed by Biotope, the market leader for advising renewable energy projects on biodiversity in France. It was initially tested on eight wind turbines in 2009 and 2010, during the autumn peaks of bat mortality. Analysis of bat fatalities showed a significant (70%) decrease in mortality with an annual loss of produced power of less than 0.1%. These results were consistent with results from similar approaches in North America. The system has since been implemented by several wind power projects across Europe and in Ontario (Canada).

Ten years on, in spite of its benefits, the interest for automated systems based on modelled behaviour remains low. Curtailment based on thresholds determined after some local monitoring of mortality and/or bat activity against weather conditions is often considered sufficient and cheaper. The reliability of the monitoring data is therefore critical and the development of sound-recognition software, such as Biotope's Sonochiro®, and its expansion outside Europe and North America is a key challenge.



Source: Lagrange et al. (2013). The presentation is accessible at: https://www.researchgate.net/publication/307174665_Mitigating_Bat_Fatalities_from_Wind-power_Plants_through_Targeted_Curtailment_Results_from_4_years_of_Testing_of_CHIROTECHC

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Case study 4

Conversion of a disused military base

Location
Toul-Rosières (France)

Mitigation hierarchy components
Avoidance, minimisation, restoration, offset and PCAs

Brief description of the project/initiative
The Toul-Rosières Solar Photovoltaic Power Plant has given a second life to a former military base in disuse. Local ecology preservation was factored into every stage of the project – from design through to construction and operations.

The site consisted of a wide variety of surfaces – bitumen, meadows, woods, buildings (control tower, storage and munitions facilities, aircraft hangars) and living quarters. The first stage in the site rehabilitation process was to prepare the land and eliminate pollution, where:

- over 1,000 samples were taken at the site to establish a diagnosis assessment of soil condition and draw up a pollution abatement plan;
- 8,000 tonnes of polluted soil were removed, as well as hydrocarbon tanks and several kilometres of pipe; and
- 280 buildings were dismantled, with asbestos removed from 170 in advance.

The site, which had been disused for a number of years, was inhabited by numerous species. Several measures, identified during the development of the project, were implemented to integrate the power plant into the surrounding landscape and preserve local ecology, including:

- conservation of the wooded areas inside and between sections of the power plant to maintain ecological corridors that allow wild animals to move around;
- installation of special shelters and nest boxes for bats to offset the demolition of asbestos containing buildings where they used to live;
- upkeep of natural habitats and sensitive environmental areas (protected plants, heritage meadows);
- planting of meadows for bees to support pollinating insects; and
- creation of landscaped afforestation and hedges around the rim of the site to integrate the power plant within its surroundings.

At the end of its operational life, the power plant will be fully dismantled, and the site will be returned to the authorities clear of any pollution.

Photovoltaic power plant has given a second life to a former military base in disuse along with pollution abatement of the field
Source: © Olivier Mousty, Toul-Rosières

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Case study 5

Protection of Montagu's harrier (*Circus pygargus*) at Chemin d'Ablis wind power plant

Location
Beauce region, including eight municipalities of the Eure-et-Loire department, France

Mitigation hierarchy component
Proactive conservation action

Brief description of the project/initiative
The centre region of France is home to many wind farms. The environmental impact assessment conducted for Chemin d'Ablis Wind Power Plant and a research programme analysing the overall impact of wind power plants in the region identified a particularly high risk to broods of Montagu's harrier (*Circus pygargus*), a heritage raptor species classified as threatened on the National Red List of France and protected in Europe at harvest time.

Harriers nest on the ground on large and dense farmlands. Broods are thus protected from their predators but are extremely vulnerable – not to wind turbines, which have little impact on this species in the region, but to the farm vehicles used for harvesting, which takes place at a time of year when young harriers are generally not yet able to fly.

EDF Renewables France proposed to join efforts to conserve the region's Montagu's harriers.

In 2014, the company entered into a partnership with a local NGO (Eure-et-Loir Nature) under which various concrete measures were taken to protect the raptor, such as:

- A search for Montagu's harrier pairs (close to 3,700 km was travelled throughout the Eure-et-Loir department) and a monitoring system;
- Monitoring of broods until the offspring fly away; and
- A campaign to inform and raise awareness among farmers and landowners about the need to fence off areas around the nests.

Seven broods were successfully protected across the Eure-et-Loir department in 2014, representing a total of 22 young Montagu's harriers.

Harrier's brood protected with fence off areas around the nests.
Source: ©EDF EN.

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Case study 6

Siting optimisation of a wind project

Location
Champagne-Ardenne region, Marne department, municipalities of Essarts-le-Vicomte and La Forestière

Mitigation hierarchy component
Avoidance and minimisation during project design phase

Brief description of the project/initiative
Portes de Champagne Wind Power Plant is located on agricultural land, with a former railway line bordered by hedgerows located on site. Forests are located directly north and east of the site. Environmental studies conducted during the project development stage identified the importance of these areas to birds and bats. The former railway line forms an ecological corridor and the forested area represents habitats for these species (nesting, hunting, breeding and migration).

The project's turbine models, number and siting were studied and evaluated to optimise the project's environmental, technical, and economic design criteria.

Adjustments were made to turbine siting to avoid and minimise the wind energy project's impact on the local habitats of birds and bats, while optimising the project's landscape integration and maintaining its technical and economic performance. These included a 200 m setback distance from the forest's edge and the railway line to minimize impacts to birds and bats.

Implementation of these measures also led to a reduction in the size of the proposed project from 12 to nine wind turbines. At the end of the permitting process (led by local authorities), and as a precautionary measure to protect biodiversity, only six turbines were installed.

The first environmental monitoring conducted at Portes de Champagne Power Plant confirmed that there was no material impact on bird life or on biodiversity at large, thus validating the efficiency of the measures implemented.

Porte de Champagne wind power project after the application of mitigation
Source: ©EDF EN.

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Case study 7

EDF France solar power plant management and servicing plans

Location
All solar power plants with environmental issues in France

Mitigation hierarchy component
Minimisation (abatement and operational controls)

Brief description of the project/initiative
EDF Renewables France developed management and servicing plans (MSP) for vegetation in 2011, which have since been implemented at all the company's solar power plants with environmental issues. Measures, such as grazing by sheep and/or mowing (by person/machinery), are designed to be site specific, accounting for local and technical feasibility, compatibility of vegetation management measures with the park's biodiversity issues, etc.

Some of the key measures employed include:

- Prohibition of vegetation upkeep between the rows of panels at certain times of the year, during nesting periods (generally mid-March to mid-July), except when there is a high risk of fire or shadows interfering with the solar panel operation;
- Mowing of the areas between panel rows is limited to only once or twice a year when grazing is not taking place;
- Upkeep of the areas under the panels, and next to the technical facilities and runways is allowed all year round; and
- A complete ban on the use of chemical pesticides.

Progress is monitored regularly to aid in continuously improving the program. This includes, among other aspects, the identification of any compliance issues such as deviations from the established mowing/grazing regimes and clarifying on any potential misinterpretations of the summarized management plan. Specific adaptive management actions are also undertaken to protect and manage the biodiversity values occurring within the solar power plants. For example, mowing regimes are regularly reviewed within a two-year period to ensure they provide adequate protection and management of a regionally protected species on site.

Sheep grazing under solar panels
Source: © EDF Renewables

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Case study 8

Understanding risks associated with unplanned renewable deployment in India, and opportunities to develop renewables without harming wildlife

Location
India

Mitigation hierarchy component
Avoidance and mitigation

Brief description of the project/initiative
India has committed to reduce emissions with a goal to increase renewable energy production to 175 gigawatts (GW) by 2022. Achieving this objective will involve rapidly increasing the deployment of solar and wind energy, while at the same time addressing the related challenges of the financing requirements, environment impacts, and power grid integration. Usually, renewable projects are based on locations where the resource potential is the highest, i.e. the sun shines the brightest and the wind blows the hardest.

A study conducted by The Nature Conservancy (TNC) and the Center for Study of Science, Technology and Policy (CSTEP) found that in India, without careful planning, more than 11,900 km^2 of forest and 55,700 km2 of agricultural land could be impacted. If development proceeds in this fashion, potential risks could emerge and create conflicts that delay projects and jeopardize investments. However, the study also found that India could meet its renewable energy target of 175 GW by 2022 by placing renewable energy infrastructure on already degraded lands, which pose lower conflict. The study shows that there are enough lower-conflict lands to generate more than 10 times the 2022 renewable energy target.

In support of this goal a tool was created – SiteRight – to improve decisions and to allow users to examine the consequences of unplanned renewable deployment and help to proactively guide avoidance of impacts to nature or people.

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Kiesecker, J., S.Baruch-Mordo, M. Heiner, D. Negandhi, J. Oakleaf, C.M. Kennedy, P. Chauhan. 2020. 'Renewable energy and land use in India: A vision to facilitate sustainable development'. Sustainability 12(1):281. Available at: https://doi.org/10.3390/su12010281

Jaisalmer Windmills in Rajasthan, India
Photo: © Nagarjun Kandukuru

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Case study 9

Collaborative approaches to minimising and offsetting impacts to vultures, Kipeto Wind Farm

Location
Kajiado County, Kenya

Mitigation hierarchy component
Working with stakeholders

Brief description of the project/initiative
Kipeto Energy PLC is developing the Kipeto Wind Power Project, a 100 MW facility comprising 60 wind turbines in Kajiado County, Kenya. The proposed wind farm is near nesting colonies of two Critically Endangered vulture species: Rüppell's vulture (*Gyps rueppelli*) and white-backed vulture (*G. africanus*). Both species regularly overfly the wind farm. Unfortunately, the risks to highly threatened vultures became known too late in project planning for an alternative site to be considered. Stakeholder concerns over potential vulture collisions with wind turbines appeared likely to delay project development.

With support from specialist consultants, developers and investors worked closely with stakeholders to understand the concerns fully and develop credible mitigation measures. On-site monitoring helped quantify the risks to vultures, and was used to develop minimisation measures and offsets aimed at achieving net gain for both species, in alignment with IFC's Performance Standard 6. Minimisation measures focus on rapid detection and removal of carcasses from the site to avoid attracting vultures to the area, and observer-led shut-down-on-demand when birds at risk are spotted. Offset measures include a suite of interventions in the wider landscape to reduce human-wildlife conflict and thus retaliatory poisoning of predators – as incidental poisoning poses the largest single threat to vulture populations in southern Kenya. Offset activities are implemented by a partnership of four conservation NGOs and the Kenya Wildlife Service, and overseen by a multi-stakeholder Biodiversity Committee.

View of the Kipeto wind farm site, central Kenya
Source: © David Wilson

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Case study 10

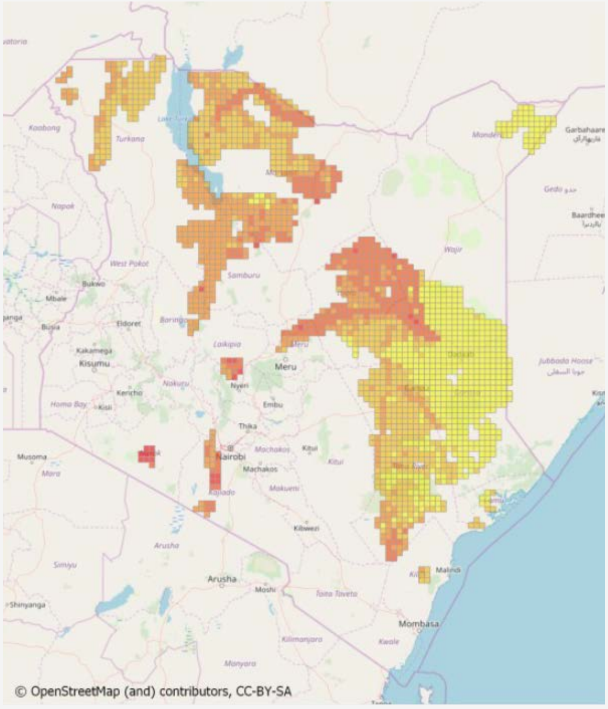
Sensitivity mapping for wind power

Location
Kenya

Mitigation hierarchy component
Avoidance

Brief description of the project/initiative
A strategic environmental assessment (SEA) for wind power and biodiversity in Kenya was undertaken by a consortium of conservation NGOs (Nature Kenya, The Peregrine Fund and BirdLife International) led by The Biodiversity Consultancy. It was undertaken on behalf of Kenya's Ministry of Energy, with funding from the United States Agency for International Development (USAID) Power Africa Transactions and Reform Programme implemented by Tetra Tech. The SEA included sensitivity mapping for biodiversity as a key component.

Following an expert workshop to identify priority at-risk bird and bat species and site types, a wide range of data was compiled to map species and site sensitivities. These included records and modelled ranges of priority species, movement data from satellite-tagged vultures, and locations of Protected Areas, Key Biodiversity Areas and wetlands. Sensitivities were mapped against potential zones for economic wind energy and overlaps with current and planned wind power developments. The assessment supports strategic planning of wind developments to minimise negative biodiversity outcomes, providing higher certainty for developers on biodiversity risks and mitigation options.



Sensitivity score categories:

Low
Moderate
High
Very high
Outstanding

Source: Mapping by BirdLife International

Figure 1. Species sensitivity categories for economic wind power areas in Kenya. Categories reflect the presence of priority species based on range maps, observations and (for vultures) movement of tagged birds

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Case study 11

Working in partnership to reduce distribution line impacts on birdlife

Location
Portugal

Mitigation hierarchy component
Avoidance and minimisation

Brief description of the project/initiative
In the Iberian Peninsula, the main biodiversity impact resulting from EDP's distribution activity is bird collision and electrocution. In 2003, EDP established a partnership with the main Portuguese environmental NGO´s and the national authority for nature and biodiversity conservation aiming to systematize internal procedures for planning, construction, and maintenance of power grids located in protected areas. This partnership is driven by a technical multi-stakeholder commission constituted by all the members that test innovative technological solutions, monitors bird impacts at national level and sets priorities for voluntary mitigation initiatives in identified critical hot spots.

Over the course of 16 years of partnership, a total of about 680 km of overhead electricity distribution lines considered critical for birdlife were subject to mitigation measures within the National Network of Classified Areas. Some vulnerable species potentially impacted by this activity are the great bustard (*Otis tarda*), the Spanish imperial eagle (*Aquila adalberti*), and the red kite (*Milvus milvus*) vulnerable to electrocution, and others such as the roller (*Coracias garrulus*) which are vulnerable to both electrocution and collisions.

Pole isolation is the most common measure implemented to reduce the risk of electrocution, while the installation of bird flight diverters such as the Firefly Bird Flapper (FBF) reduces the risk of collision. Monitoring studies have demonstrated their level of effectiveness, with rotator type achieving 79% average effectiveness, followed by FBF ribbon type with 77% and FBF double spiral, with 40%.

Pole isolation to avoid electrocution; and FBF ribbon type to avoid collisions installed on powerline in Portugal.

Source: © EDP Renewables

The successfulness of the partnership relies on this multi-stakeholder approach with very concrete roles, where financial and human resources are optimized around a common goal. With an initial focus on mitigation, the work of this commission strongly influenced the Portuguese Technical Guidelines for mitigating bird impacts from power lines, being used at the planning and construction stage.

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Case study 12

Contributing towards the conservation of the endangered Iberian wolf

Location
Trás-os-Montes and Beira Alta region, north and south of the Douro River Valley, Portugal

Mitigation hierarchy component
Offsets and proactive conservation actions

Brief description of the project/initiative
The Iberian wolf (*Canis lupus signatus*) is a subspecies endemic to the Iberian peninsula, listed as nationally endangered in Portugal. Threats to the species include development of roads and renewable energy infrastructure, including wind power, as well as frequent forest fires. Since 2000 this species has been specifically mentioned in Portugal's environmental and social impact assessment (ESIA) legislation.

Recognizing the challenge of balancing wind power development with the protection of the species, EDP Renewables, along with other wind power companies operating in the region, funded the Association for the Conservation of the Iberian Wolf Habitat (ACHLI) in 2006. The aim is to collectively preserve natural and cultural landscapes in sensitive areas within the region by supporting projects that benefit Iberian wolf habitat conservation whilst also recognising the socio-economic needs of the region (essential for the long-term project success in many cases).

The ACHLI management approach is based on a multi-stakeholder participatory process that strongly advocates the involvement of local players, such as municipalities, parish councils, owners, hunting zone management entities, local NGOs and others. Conservation and awareness actions include increasing the availability of natural prey, the reduction of human disturbance and measures to address human-wildlife conflict.

Since 2006, ACHLI has actively participated in the project/construction stages of 102 wind farms, 10 of which are from EDP Renewables, and only 46 of which had a mandatory environmental impact assessment. All others were voluntary commitments by the wind farm developers. More than 218 conservation projects were developed and in 2010, the success of ACHLI led to a territorial expansion of its activities beyond the initial wind power region.

The collective approach has provided an effective means to work collectively on this common challenge. Synergies allowed the conservation projects to focus beyond members' own responsibility, benefiting this iconic Portuguese endangered species.

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Case study 13

Radar and visual assisted shut down of turbines at Barão de São João Wind Farm

Location
Barão de São João, Portugal

Mitigation hierarchy component
Minimisation

Brief description of the project/initiative
At the Barão de São João wind farm in Portugal, implementation of shutdown on demand (SDOD) resulted in only two fatalities of soaring birds over the first 10 years of operations. Between 2010 and 2019, only two soaring birds died from collision with the wind turbines: one booted eagle (*Hieraaetus pennatus*) in 2015, and one European honey-buzzard (*Pernis apivorus*). Shutdown was led by observers at up to five sites around the wind farm and two more vantage points within the wind farm; which was supported by a radar to detect and track birds at larger distances (6–8 km). Observers are present throughout the southward migration season, with the radar support only during the highest migratory period (15September–15November). In the first three years, shutdown orders were delivered from the observers to the control centre, who then shut down turbines. Observers can directly shut down turbines through direct access to the SCADA system. Direct access to SCADA has allowed adaptive management and increased experience of the monitoring team. Equivalent annual shutdown period has been decreasing constantly, from over 100 h in 2010 to less than 10 h in 2017–2020 (variation 0.85 h–11 h). The criteria to trigger SDOD are:

Intense migratory flux of soaring birds (more than 10 birds) detected in one day close to or approaching the wind farm area;

Flocks of migrating soaring birds (three or more individuals per flock) of birds detected close to or approaching the wind farm area detected at high collision risk flight heights;

Threatened soaring bird species detected close to or approaching the wind farm area at high collision risk flight heights. This includes a list of seven species threatened at the national level: the black stork (*Ciconia nigra*) (see photo), the golden eagle (*Aquila chrysaetos*), the Spanish imperial eagle (*Aquila adalberti*), the cinereous vulture (*Aegypius monachus*), the osprey (*Pandion haliaetus*), the lesser kestrel (*Falco naumanni*) and Bonelli's eagle (*Aquila fasciata*); and

Imminent collision risk of a migratory soaring bird with one of the turbines even if previous criteria not met.

Reference
Tomé, R., Canário, F., Leitão, A., Pires, N. and Repas, M. (2017). 'Radar assisted shutdown on demand ensures zero soaring bird mortality at a wind farm located in a migratory flyway'. In *Wind Energy and Wildlife Interactions,* pp. 119–133. Springer International Publishing AG.

Black stork (Ciconia nigra) flying close to a wind turbine in the Barão de São João wind farm
Photo: ©Ricardo Correia/STRIX

Flock of griffon vultures (Gyps fulvus) flying close to a wind turbine during a shutdown operation in the Barão de São João wind farm
Photo: ©Ricardo Correia/STRIX

Observer monitoring the movements of soaring birds at the Barão de São João wind farm
Photo: ©Alexandre H. Leitão/STRIX

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Case study 14

Working in partnership to protect cinerous vultures

Location
Northwest Portugal and Spain

Mitigation hierarchy component
Working with stakeholders

Brief description of the project/initiative
In January 2019, a juvenile cinereous vulture (*Aegypius monachus*) was recovered in the Porto area, north-west of Portugal, and was GPS-tagged by the LIFE Rupis Project. This project tracks the movement of vultures, including the endangered Egyptian vulture (*Neophron percnopterus*), to combat their most pressing threats, food shortages, poisoning, habitat degradation, electrocution and collision with wind turbines. The GPS tracker identified that the vulture was frequently flying within 100 m of the turbines at the Olivento Wind Farm in north-west Spain. The Vulture Conservation Foundation (VCF) quickly contacted colleagues at the Sociedade Portuguesa para o Estudo das Aves (SPEA), who then approached the Sociedad Española de Ornitología (SEO), to notify the Department of the Environment of the Xunta de Galicia. Through international collaboration by the VCF, the Department of the Environment of the Xunta de Galicia, SEO, SPEA and the MAVA Foundation, a temporary shutdown on demand (SDOD) was quickly implemented to prevent a collision with the vulture. This partnership continues to monitor birds through GPS tracking and observation at the wind farm site to implement further SDODs as necessary. Such actions contribute to vulture conservation in the area, preventing the further species declines and potential local extinctions.

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Case study 15

Strategic Environmental Assessments for South African Renewable Energy Development Zones (REDZ) and Electricity Grid Infrastructure Corridors

Location

Across South Africa

Mitigation hierarchy component

Avoidance through early planning

Brief description of the project/initiative

Strategic Environmental Assessments (SEA) were carried out to identify Renewable Energy Development Zones (REDZ) to facilitate the growth of renewable energy in South Africa. The REDZs were identified through a holistic approach, considering technical, environmental and socio-economic criteria. The first SEA identified eight REDZs for wind and solar photovoltaic energy development (DEA, 2015; CSIR, 2017). The second SEA (DEFF, 2019a) identified additional REDZs that specifically targeted previously mined areas where brownfields development could make use of existing infrastructure while also contributing towards rehabilitation of these areas.

The identification of REDZs involved characterising and mapping positive or ‘pull’ factors beneficial for renewable energy development. These include, for example, the abundance of wind and solar energy resources and access to power corridors and other facilities, and complemented by mapping negative or ‘push’ factors, such as environmental features and areas, which may be sensitive to the development of large-scale wind or solar facilities (DEA & CSIR). Features considered critically important for the environmental constraints mapping included protected areas, forests, critical biodiversity areas and the presence of important bird and bat roosts and feeding sites. Within each REDZ, development is restricted within defined areas of high biodiversity sensitivity.

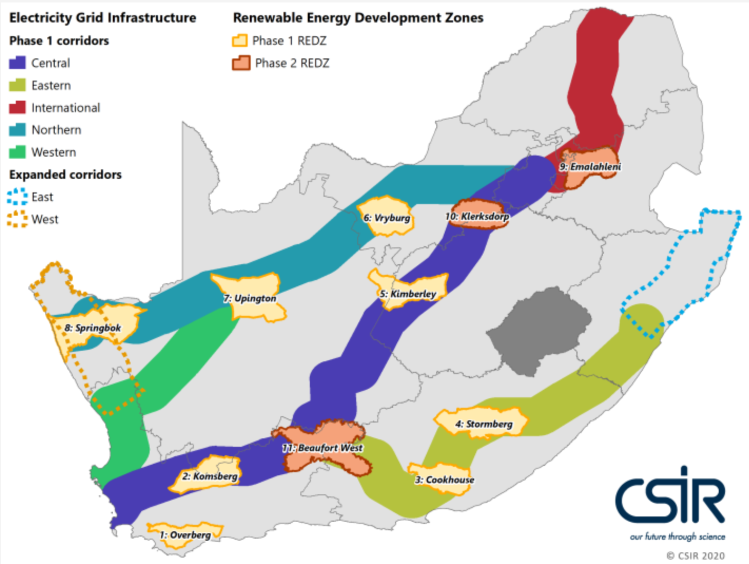

Figure. Renewable Energy Development Zones and Electricity Grid Infrastructure Corridors as identified in the Strategic Environmental Assessments conducted by CSIR for the national Department of Environmental Affairs in South Africa

For example, 50 km buffers were designated around endangered Cape vulture (*Gyps coprotheres*) colonies, roost sites and managed feeding sites. Lastly, a prioritisation exercise was carried out to ensure that proposed developments aligned with industrial needs.

Two SEAs for electricity grid infrastructure (DEA, 2016; DEFF 2019b) complemented the SEAs for wind and solar energy. Biodiversity mitigation included planning power line corridors to avoid impacts on sensitive bird species.

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_____ (2019b). Strategic Environmental Assessment for the Expansion of Electricity Grid Infrastructure Corridors in South Africa. CSIR Report Number: CSIR/SPLA/EMS/ER/2019/0076/B. ISBN Number: ISBN 978-0-7988-5648-5. Stellenbosch and Durban. Available at: https://sfiler.environment.gov.za:8443/ssf/s/readFile/folderEntry/29212/8afbc1c772743944017376c3d2c61f70/1595409805381/last/SEA_for_Expansion_EGI_Corridors_SA.pdf

The Cape griffon or Cape vulture (Gyps coprotheres), also known as Kolbe's vulture, is an Old World vulture endemic to southern Africa. This large vulture is dark brown except for the pale wing coverts. The adult is paler than the juvenile, and its underwing coverts can appear almost white at a distance. The species is listed as "Vulnerable", the major problems it faces being poisoning, disturbance at breeding colonies and powerline electrocution.
Source: Heather Paul (CC BY-ND 2.0) https://www.flickr.com/photos/warriorwoman531/8129503570

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Case study 16

The Rich North Sea programme

Location
Dutch North Sea

Mitigation hierarchy component
Offsetting and proactive conservation actions

Brief description of the project/initiative
The Rich North Sea (De Rijke Noordzee, DRN) aims to; i) develop reefs within offshore wind farms (OWFs) in the North Sea; ii) build a strong scientific knowledge base about ecosystem development in the North Sea; and iii) to create a "Nature Development Toolbox" containing the most required information on nature development in OWFs in the Dutch North Sea, which can serve as a guide for future offshore energy projects. DRN aims to make nature development in OWFs the new standard. The programme aims to solve issues in the supply chain of reef building organisms for biodiversity enhancement projects, allowing roll-out on a larger scale. Simultaneously, new policies to stimulate the combination of nature development and offshore wind energy will be advocated for. The long-term goal is the creation of resilient underwater life and nature enhancement options as the new standard in the construction of OWFs.

To achieve these aims, Dutch offshore wind farms biodiversity enhancement options will be implemented at six locations. Examples of biodiversity enhancement options are artificial reefs, added substrate or the use of life material such as European flat oyster (*Ostrea edulis*). Target species range from reef building species (such as the Ross worm *Sabellaria spinulosa* and the sand mason worm), reef-associated species (such as anemone species that only grow on hard substrates), and fish species (such as the goldsinny wrasse *Ctenolabrus rupestris* that builds a nest in a reef) and reef-benefitting species (such as cod *Gadus morhua* and sea bass *Dicentrarchus labrax*) (Bureau Waardenburg, 2020). The programme runs in close cooperation with the offshore wind sector and scientific research partners.

Reference
Bureau Waardenburg. 2020. Options for biodiversity enhancement in offshore wind farms. Knowledge base for the implementation of the Rich North Sea Programme. Bureau Waardenburg Rapportnr.19- 0153. Bureau Waardenburg, Culemborg. Available at: https://www.buwa.nl/fileadmin/buwa_upload/Bureau_Waardenburg_rapporten/2020/18-0660_The_Rich_North_Sea-_options_for_biodiversity_enhancement_in_OWFs_07022020-reduced.pdf

Further information
www.derijkenoordzee.nl

Underwater scene depicting artificial reefs on the seabed of an offshore wind farm in the Dutch North Sea
Photo: © The Rich North Sea

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Case study 17

North Sea flat oyster restoration

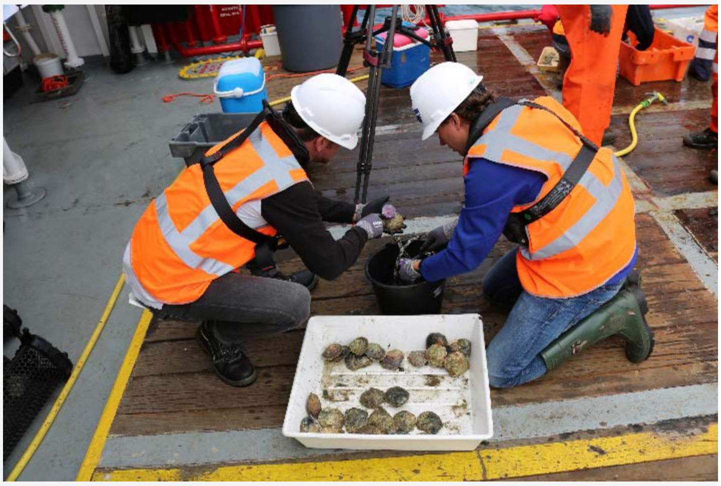
Location
North Sea, The Netherlands

Mitigation hierarchy component
Proactive conservation actions

Brief description of the project/initiative
Wind farms can be designed in ways that take advantage of their multi-use capacity through the reserve and reef effects. By using nature-inclusive building materials in areas around offshore windfarms, where bottom trawling is prohibited, wind farms can be co-designed for oyster bed restoration. This can assist in mitigating biodiversity impacts and enhancing ecosystem services and functioning, including future seafood production, while meeting the economic demand for energy.

The Ministry of Economic Affairs of the Netherlands has partnered with World Wide Fund for Nature (WWF), ARK Nature and Wageningen Marine Research, among others, to establish the Flat Oyster Consortium. This collaboration has carried out a pilot project to explore feasibility and optimise the design and management of flat oyster restoration in offshore wind farms in the Dutch North Sea. Due to overfishing and habitat destruction through bottom trawling and disease, the epibenthic shellfish reefs, which were once plentiful in the area, are now almost absent.
By constructing artificial reef structures in the undisturbed seabed around wind farm foundations and supplementing the areas with flat oysters, the project was able to cultivate a functioning population of flat oysters and attract various fauna.

Reference
Didderen, K., Lengkeek, W., Kamermans, P., Deden, B., Reuchlin-Hugenholtz, E., Bergsma, J.H., van Gool, A.C., van der Have, T.M., Sas, H. (2019). *Pilot to actively restore native oyster reefs in the North Sea: comprehensive report to share lessons learned in 2018*. Bureau Waardenburg. Available at: https://www.ark.eu/sites/default/files/media/Schelpdierbanken/Report_Borkumse_Stenen.pdf



At the Eneco Luchterduinen offshore wind farm, oysters are cleaned and measured after six months at the bottom of the North Sea.
Photo: ©The Rich North Sea

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Case study 18

Broom Hill partnership supporting a natural reserve

Location
England, County Durham, UK

Mitigation hierarchy component
Offset

Brief description of the project/initiative
The Broom Hill Wind Power Plant, in north-eastern England, is located adjacent to the Stanley Moss Nature Reserve, a lowland blanket bog that was in a state of decline. An innovative and unique partnership has been agreed with the Durham Wildlife Trust in securing long-term biodiversity benefits.

Stanley Moss is one of the few remaining blanket peat bogs found in the lowlands of County Durham. It was once much larger but has been significantly reduced due to opencast coal mining, forestry and agricultural activity.

Heather, bilberry and cotton grass carpet the bog and where the surface is waterlogged sphagnum mosses thrive. More unusual species, such as crowberry and hare's-tail cotton grass, can also be found.

The site is important for birds with breeding meadow pipits, skylarks and lapwings and there have been frequent sightings of short-eared owls, black and red grouse and large numbers of snipe and curlew.

During the development process of the Broom Hill Wind Power Plant, a partnership was agreed and implemented to support Durham Wildlife Trust in the acquisition of the Stanley Moss Nature Reserve.

As part of this partnership, 50% of the employment costs of a wildlife officer are financed for the lifetime of the wind farm. The officer's role is to manage the Natural Reserve.

Together, Durham Wildlife Trust and EDF Energy Renewables developed a habitat management plan for the wind farm and the adjacent nature reserve. The site is rehabilitated through annual management work.

Scrub encroachment continues to be an issue and requires continued management effort. Grazing overall maintains the site in a favourable condition. Bog mosses are now more prevalent and the site is wetter as a result of the grip blocking and conifer removal.

The restoration of two parcels has seen almost a two-fold increase in the available heath and bog habitat on site. In addition to the restoration of the bog, heath and acid grassland habitat, there have been notable species records. Green hairstreak butterfly and Emperor moth both continue to be recorded on the site. Bird records include breeding curlew, lapwing, skylark, meadow pipit, cuckoo, and short-eared owl. Lecking black grouse have been recorded since 2016.

Cotton Grass, Stanley Moss Nature Reserve, Broom Hill Wind Power Plant
Source: © EDF Renewables

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Case study 19

Defra Biodiversity Metric for measuring losses and gains

Location
Across the UK

Mitigation hierarchy component
Assessment and monitoring

Brief description of the project/initiative
Defra Biodiversity Metric, developed in 2012 and updated in 2019, aims to provide developers, planners and other interested parties with a means to account for biodiversity losses and gains that result from development projects. The metric is a habitat-based approach to determine a proxy biodiversity value, which provides a consistent way for stakeholders to measure and evaluate potential impacts of developments as well as the effectiveness of mitigation measures. The metric is calculated pre- and post-interventions being applied and takes into account both the size and quality of the habitats which fall within the development site, as well as offsets implemented elsewhere. The quality of a habitat is considered according to four components: i) distinctiveness; ii) condition; iii) strategic significance; and iv) connectivity. The metric also incorporates risks in terms of how difficult the habitat type is to create, how long it would take to be established and whether any compensation can be undertaken sufficiently close to the site.

Reference
Crosher, I., Gold, S., Heaver, M., Heydon, M., Moore, L., Scott, S., Stone, D. and White, N. (2019). *The Biodiversity Metric 2.0: Auditing and accounting for biodiversity value. User guide (Beta Version, July 2019).* Available at: https://doi.org/10.13140/RG.2.2.29888.69123

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Case study 20

Marine mammal protection during offshore wind power plant construction

Location
North Yorkshire County, off the coast of Redcar (North Sea), England, UK

Mitigation hierarchy component
Species conservation measures in offshore wind farm construction

Brief description of the project/initiative
A comprehensive environmental impact assessment (EIA) was conducted during the development stage of the TEESSIDE offshore wind power project. Cetacean species protected under UK law that were found to be present in the area include the harbour porpoise, white-beaked dolphin, bottlenose dolphin, minke whale, as well as local colonies of both grey and harbor seals and occasionally basking sharks.

The findings of the EIA were integrated into the project design and construction process. A specialist team was deployed on site to conduct monitoring and ensure that the area in the vicinity of the piling activities was clear of marine mammals before work started each day. For example:

- Prior to each piling exercise, a dedicated vessel was used to circle the piling site at a distance of 250 m, to ensure that there were no marine mammals near the piling operations;
- Visual watchkeeping of the sea for marine mammals was carried out; and
- A hydrophone was dropped into the water to listen for vocalisations made by whales and dolphins.

Once the area had been monitored for 30 minutes and marine mammals had not been detected, piling work could start. If any marine mammals entered the area, the start of work was delayed until the animal was clearly seen to leave.

In addition, pile driving works were not planned during the most important period of bird activity in the area. Other special construction and logistical activities were also undertaken to maintain the integrity of special local coastal features.

UK offshore wind farm
Photo: ©EDF-Brown Graham Chapman Brown Photography

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Case study 21

Southill Community Energy

Location
Oxfordshire, England, UK

Mitigation hierarchy component
n.a.

Brief description of the project/initiative
Renewables projects lend themselves to community investment, be this partial or complete ownership. In Europe, there are many examples of solar farms and wind farms being in community ownership, ensuring communities engage both financially and practically in the management of their facility. Such arrangements usually entail a moderate financial return for investors, and in many cases community members will participate in land management and wildlife monitoring activities.

Southill Community Energy is a 'community benefit society' run by community members to empower local people and organisations in reducing their carbon emissions. Their aim is to invest in sustainability by using surplus income generated from Southill Solar to invest locally to support local low-carbon community initiatives. Among other projects, the funds have been used to enhance local biodiversity and have supported the establishment of a community-owned solar farm which generates clean energy for over 1,100 homes in Charlbury.

By enhancing hedgerows and wildflower meadows in and around the solar energy site the project has improved biodiversity and ecosystem services, such as pollination services, for the community. Planting orchards, bee keeping and managing vegetation beneath the solar panels have also benefitted the community by providing fruit and honey for people, and forage livestock and wildlife throughout the year.

For further information, please see: https://southillcommunityenergy.coop

Beekeeping at Southill
Source: G Parker, Wychwood Biodiversity (2017)

Planting the Southill community orchard.
Source: © Guy Parker, Wychwood Biodiversity (2017)

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Case study 22

Southill solar farm

Location
Oxfordshire, England, UK

Mitigation hierarchy component
Offsetting and additional conservation actions to achieve a net gain for biodiversity

Brief description of the project/initiative
Southill is a community-owned solar farm built in 2016. Prior to its construction, Southill Community Energy and Wychwood Biodiversity developed a land management plan to deliver a net gain for biodiversity, focusing upon limestone grassland and its associated invertebrate life. The solar farm was built on two arable fields which, apart from their mature hedges and a small area of meadow to the north, were unremarkable from a wildlife perspective.

Following construction, three grassland habitats were developed: first, limestone grassland seeded along the eastern portion of the site; second, tussock grassland and wild flowers around the entire margin of the site; and third, a traditional grazing meadow beneath the solar arrays. A pollinator crop and a winter bird seed mix were seeded at the southern end of the site. The hedgerows, grassland habitats and crop areas are all managed to provide a diversity of roosting, nesting and foraging habitats through the year. The tussocky grassland at the margin of the site provides cover and a rich source of invertebrates for young birds in the spring and summer, and remains uncut in winter as a refuge for invertebrates. The limestone grassland is botanically diverse and provides a rich source of forage for pollinators and nesting for skylarks. Hedgerows are managed to encourage flowering and fruiting.

Southill is surveyed annually by Wychwood using systematic monitoring. Evidence from the first three years indicates that botanical diversity is increasing (Figure 1), and the abundance of both bumblebees and butterflies is also increasing (Figure 2).

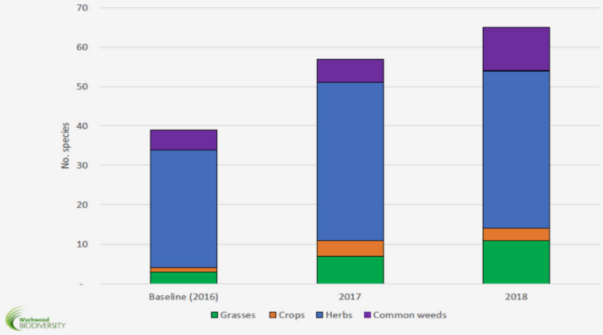

Figure 1. Species richness of four plant groups compared between 2016, 2017 and 2018. © Wychwood Biodiversity

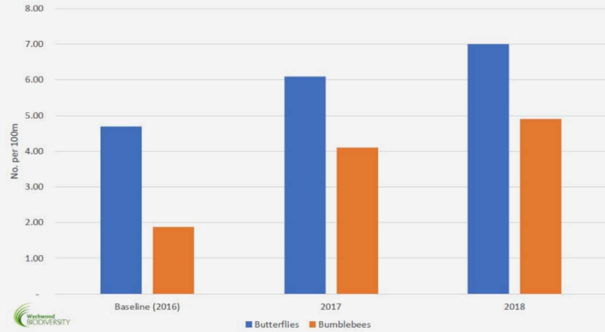

Figure 2. Comparing encounter rate per 100 m for butterflies and bumblebees between 2016, 2017 and 2018. © Wychwood Biodiversity

Meadows surrounding Southill solar farm.

Meadows surrounding Southill solar farm
Photo: © Guy Parker, Wychwood Biodiversity (2017)

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Case study 23

Docking Shoal denied consent due to potential cumulative impacts on sandwich terns

Location

UK

Mitigation hierarchy component

Early planning/avoidance

Brief description of the project/initiative

In 2012 the Docking Shoal offshore wind farm in the outer-Wash area of the UK was refused consent due to concerns about cumulative impacts on sandwich terns (*Thalasseus sandvicensis*) at the North Norfolk Coast Special Protection Area (SPA). When Centrica was awarded an agreement from The Crown Estate in 2004, was subject to consent, it was to develop a Round 2 offshore wind farm in the greater Wash area. A total of five wind farms were being considered or already being developed in this area. This wind farm was sited and planned close to two existing wind farms in the area of Lincolnshire and Race Bank.

Due to the presence of an important sandwich tern breeding area, hosting 40% of the national breeding population, a modelling study was commissioned to assess the potential impacts to this species. The study found that the new development would pose population-level threats to the sandwich tern because of collision with wind turbines, when considering the cumulative impacts from multiple wind farms in the area. The population modelling study estimated a mortality rate of 102–127 birds per year, exceeding the threshold of 94 birds.

Reference

Caldow,R., Mackenzie, A., Allen, S. and Perrow, M.R. (2019). 'Use of a risk-based approach towards the assessment of population-level consequences of predicted collision mortality of a breeding seabird'. In M.R. Perrow (ed.). *Wildlife and Wind Farms, Conflicts and Solutions Volume 4 Offshore: Monitoring and Mitigation,* pp. 150–155. Exeter, UK: Pelagic Publishing.

King, S. (2019) 'The stakeholder perspective on the use of collision risk modelling and population modelling in the consenting process for an offshore wind farm'. In M.R. Perrow (ed.). *Wildlife and Wind Farms, Conflicts and Solutions Volume 4 Offshore: Monitoring and Mitigation*, pp. 136–138. Exeter, UK: Pelagic Publishing.

Mitchell, P I, Newton, S, Ratcliffe, N and Dunn, T E. (2004). *Seabird populations of Britain and Ireland (Results of the Seabird 2000 Census 1998–2000).* London, UK: T&D Poyser.

Mitchell, P I, Newton, S, Ratcliffe, N and Dunn, T E. (2004). *Seabird populations of Britain and Ireland (Results of the Seabird 2000 Census 1998–2000* London, UK: T&D Poyser.

Case study 24

Operational controls to reduce attractiveness of windfarm to raptors

Location
Scotland

Mitigation hierarchy component
Minimisation

Brief description of the project/initiative
In Scotland, opening up commercial forestry to wind farm development through clear-felling of turbine sites can create suitable foraging and nesting habitat for raptors close to turbines. This can attract threatened birds (hen harrier, merlin and short-eared owl) to areas where forestry is being 'opened up', increasing collision risk. Recommendations for measures to limit suitability for threatened birds include:

- Reducing suitability for nesting by maintaining ground vegetation below 30 cm in open areas within 500 m of turbines;
- Maintaining forest corridors between the wind farm and adjacent breeding areas to produce a barrier effect dissuading entry into the wind farm site;
- Managing habitat away from proposed turbines to make it more suitable for foraging and/or nesting raptors (in comparison to areas closer to turbines); and
- Enhancing habitat away from turbines to make it more suitable for foraging and/or nesting raptors. Appropriate sites would need to provide a sufficiently wide enough area of good quality foraging and nesting habitat to help lure birds away.

Reference
Scottish Natural Heritage (2016). *Wind farm proposals on afforested sites– advice on reducing suitability for hen harrier, merlin and short-eared owl* (p. 9). [Guidance note]. Scottish Natural Heritage.

Hen harrier chicks, Langholm Moor, Dumfries and Galloway Area Photo: ©Lorne Gill/SNH (For information on reproduction rights, please contact the Scottish Natural Heritage Image Library on Tel. 01738 444177 or www.snh.org.uk).

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Case study 25

"Site Wind Right" online map

Location
USA - states of Montana, Wyoming, Colorado, New Mexico, Texas, Oklahoma, Kansas, Nebraska, South Dakota, North Dakota, Minnesota, Iowa, Missouri, Arkansas, Illinois, Indiana, Ohio

Mitigation hierarchy component
Avoidance

Brief description of the project/initiative
The Great Plains in the USA have been identified as having promising wind resources and may be key for the development of the country's wind energy capacity. The ample wind resources in this area have the potential to provide clean, low-impact energy to meet the growing demand. This area is also home to some of the best remaining grassland habitat in the USA, supporting a variety of unique biodiversity such as bison, pronghorn antelope, deer and prairie chickens.

The Nature Conservancy (TNC) is paving the way for the expansion of renewable energy by supporting policy and incentives for low-impact renewable energy development and advancing the science of low-impact siting. Part of this strategy is the Site Wind Right map project, an interactive online map that incorporates information from datasets of wind resources, wildlife habitat, current land use and infrastructure to help inform wind energy siting decisions in the area. If used during early planning stage, this map can assist developers, investors and other stakeholders to identify areas with the highest potential for development with the lowest potential for conflict with conservation interests, thereby meeting climate and conservation goals while supporting sustainable development.

Reference

Obermeyer, B., Manes, R., Kiesecker, J., Fargione, J., Sochi, K. (2011). 'Development by Design: Mitigating Wind Development's Impacts on Wildlife in Kansas'. *PLoS ONE* 6(10): e26698. https://doi.org/10.1371/journal.pone.0026698

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For further information, please see: https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/site-wind-right/ and https://www.nature.org/content/dam/tnc/nature/en/documents/SWR_Methods_20190703.pdf

Aerial view of the Elk River Wind Project near the small town of Beaumont, in the southern Flint Hills region of Kansas (this 150 MW wind farm came on-line in December 2005).
Photo: © Jim Richardson for The Nature Conservancy

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Case study 26

Longhorn Wind Power Plant raptor mitigation through prey removal

Location
Briscoe and Floyd Counties, Texas, USA

Mitigation hierarchy component
Minimisation during operation

Brief description of the project/initiative
Longhorn is an operational wind power plant in Texas that is located within the range of many raptor species, including the bald and golden eagle. A prey removal programme has been implemented to keep raptors away from the wind power plant area.

Raptors may congregate at a wind power plant to prey on carrion and small mammals. It is also understood that raptors are at higher risk of collision when pursuing prey. The removal of prey enticements can be a very effective method to keep raptors away from a wind power plant area.

Before the construction of the Longhorn Wind Power Plant, specific studies were conducted on site as part of the project development process, in order to assess raptor activity.

These studies indicated that raptor use was relatively low in the future wind farm area, particularly for bald and golden eagles. Nevertheless, to limit the potential impact of the project, a prey removal program was identified and developed for the power plant, as part of its Bird and Bat Conservation Strategy and as an effective measure to minimise attracting eagles and other raptors to the site.

A protocol was developed and is being implemented for use during the construction and operation of the wind power plant to remove carrion and other prey enticements from the wind power plant site.

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Case study 27

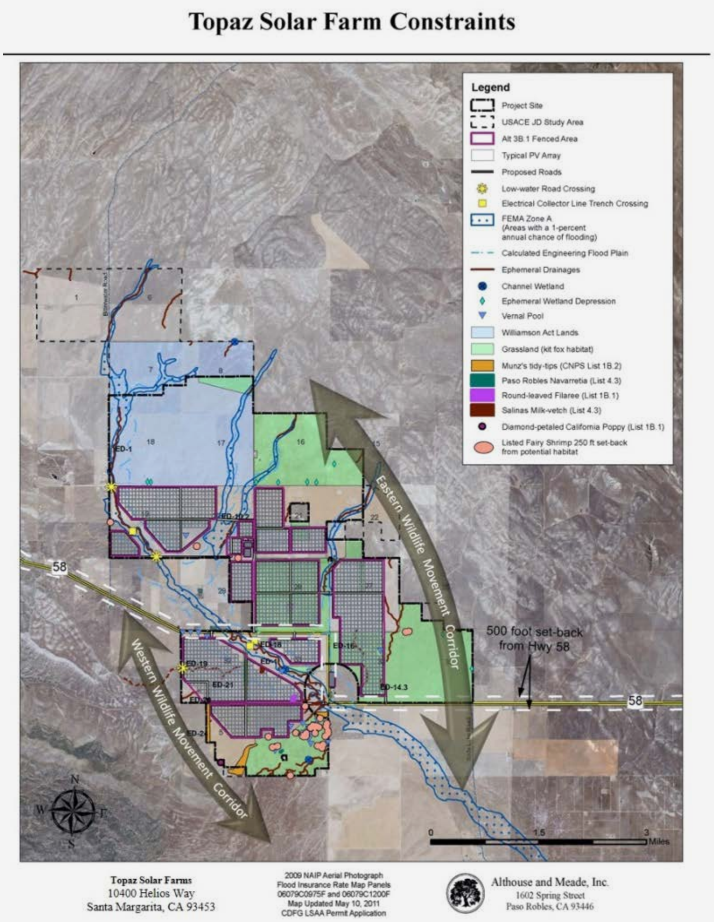
Avoidance through project design, Topaz Solar Farm

Location
San Luis Obispo County, California, USA

Mitigation hierarchy component
Avoidance

Brief description of the project/initiative
The 550 MW Topaz solar PV farm is located in grasslands and low productivity agricultural land in central California. This project was assessed to have the potential for significant impact to protected animal and plant species in the region, such as the San Joaquin kit fox (*Vulpes macrotis mutica*), pronghorn antelope (*Antilocapra americana*) and tule elk (*Cervus canadensis nannodes*).

The solar PV farm project was designed to avoid sensitive areas to biodiversity, conserve wildlife habitat and minimise disturbance. Wildlife movement corridors were preserved to the east and west of the site to enable wildlife to pass freely between the solar blocks.



Reference
Sinha, P., Hoffman, B., Sakers, J. and Althouse, L. (2018). 'Best practices in responsible land use for improving biodiversity at a utility-scale solar facility'. *Case Studies in the Environment* 2(1): 1–12. https://doi.org/10.1525/cse.2018.001123

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Case study 28

Minimisation by operational controls, Topaz Solar Farm

Location
San Luis Obispo County, California, USA

Mitigation hierarchy component
Minimisation

Brief description of the project/initiative
The 550 MWp Topaz solar PV farm is located in grasslands and low productivity agricultural land in central California. Good practice mitigation and adaptive management practices were implemented to avoid and minimise impacts to grassland habitat, including:

- Actively managing grassland habitat for grazing and nesting for threatened mammals and raptors;
- Controlling invasive plant species by a combination of grazing management and targeted spot spraying of herbicides;
- General monitoring and documentation of the status of various species of concern to inform ongoing species management practices.

Reference
Sinha, P., Hoffman, B., Sakers, J. and Althouse, L. (2018). 'Best practices in responsible land use for improving biodiversity at a utility-scale solar facility'. *Case Studies in the Environment* 2(1): 1–12. https://doi.org/10.1525/cse.2018.001123

Vegetation under PV test arrays and in alley between arrays
Source: © Parikhit Sinha, 2011

Vegetation management by grazing sheep
Source: © Parikhit Sinha

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Case study 29

New York State Offshore Wind Environmental Technical Working Group (E-TWG)

Location
East Coast (Massachusetts to North Carolina), USA

Mitigation hierarchy component
Avoidance through early planning

Brief description of the project/initiative
Offshore wind energy is a burgeoning marine industry in the United States and is currently being driven by state goals, including New York State's goal of 9,000 MW by 2035. To help guide environmentally responsible and cost-effective development of offshore wind energy, New York State formed the Environmental Technical Working Group (E-TWG) in 2018 as a solutions-oriented advisory group. Comprised of environmental non-governmental organisations, offshore wind developers, and federal and state agencies, the E-TWG's mission is to foster transparent, collaborative processes to identify and address priority issues relating to wildlife monitoring and mitigation, with the goals of both improving outcomes for wildlife and reducing permitting risk and uncertainty for developers. These activities have included:

- Identification of research needs and coordination;
- Development of wildlife best management practices;
- Consultations on offshore wind environmental mitigation plans; and
- Creation of a framework for a regional wildlife science fund.

Under the direction of the E-TWG, topically-focused Specialist Committees have brought together science-based subject matter expertise to develop collaborative guidelines or other products that inform or advance environmentally responsible development of offshore wind. The E-TWG has also supported topical workshops and other communication tools to improve coordination and information dissemination to the broader stakeholder community. The successes of the E-TWG are due, in part, to:

- Early and effective engagement with diverse stakeholders that are representative of their constituencies and supportive of the E-TWG mission;
- Clear goals and structure, with stakeholder input leading to actionable tasks that staff can execute; and
- Support staff, including technical experts and professional facilitators.

Bird and Bat Scientific Framework workshop organised by NYSERDA (March 2020)
Source: © Kate McClellan Press

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Case study 30

Factoring in concerns for Critically Endangered North Atlantic right whales during offshore wind energy site–characterisation, construction and operations

Location
East Coast, USA

Mitigation hierarchy component
Avoidance

Brief description of the project/initiative
Many large-scale offshore wind developments on the East Coast of the USA are advancing in the permitting process. This region is also a key area for the now critically endangered North Atlantic right whale (NARW) annual critical habitats and migration routes. In order to recognise concerns and potential impacts for this species around renewable energy development and promote the best practices for NARW, several environmental organisations are expressing a greater need for a series of additional best practices during site-characterisation, construction and operation of offshore wind farms.

Some recommendations include:

- site selection to avoid critical NARW habitat, potential seasonal and temporal restrictions on construction (for example, during high densities of NARW presence and acoustic detections);
- monitoring 1,000-mile exclusion zones during construction for NARW activity, vessel speed restriction to 10 knots for the lifetime of the project;
- use of effective acoustic real-time monitoring for needed enhanced mitigation;
- reduction of underwater noise during site-characterisation and during construction through gravity foundations and/or noise reduction and attenuation measures; and
- consideration of materials and installation methods.

Recommended best practices to better protect NARW also include commitments for additional scientific research and long-term monitoring, as well as contribution to wider conservation efforts for this species.

For further information, please see: https://www.nrdc.org/sites/default/files/best-management-practices-north-atlantic-right-whales-during-offshore-wind-energy-construction-operations-along-us-east-coast-20190301.pdf

North Atlantic right whale and calf
Source: ©Florida Fish and Wildlife Conservation Commission under NOAA permit #15488

A North Atlantic right whale with its tail flukes above the water's surface
Source: ©Georgia Department of Natural Resources under NOAA permit #15488

A North Atlantic right whale at the surface with its mouth open
Source: © Georgia Department of Natural Resources under NOAA permit #15488

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Case study 31

Mining the Sun Initiative – Mojave Desert

Location
Mojave Desert, California, USA

Mitigation hierarchy component
Avoidance

Brief description of the project/initiative
Nevada, USA is one of the world's most promising areas for solar energy, where large-scale developments are proposed in order to satisfy the growing energy demand. However, to mitigate the potential impacts to biodiversity, developments need to be carefully sited. The Nature Conservancy (TNC) is working together with companies, government agencies and local communities to inform decision making in the placement of solar energy developments.

Through their Mining the Sun Initiative, TNC is facilitating the development of solar energy sites on brownfields, including old mine sites, landfills and other previously developed areas, rather than on natural sites which are important for ecosystem services and biodiversity. The state of Nevada is estimated to have over a million acres of brownfields sites. This would be sufficient to reach the 50% renewable portfolio standard for the state many times over, without developing natural areas or increasing habitat loss for sensitive biodiversity. Through early planning, developments can make use of similar siting strategies in order to mitigate biodiversity impacts and balance conservation and economic needs.

For further information, please see: https://www.nature.org/en-us/about-us/where-we-work/united-states/nevada/programs/mojave-desert-program/

Reference

The Nature Conservancy (TNC) (2020). Mining the Sun. Finding a path to smart renewable energy development in Nevada. Available at: https://www.nature.org/en-us/about-us/where-we-work/united-states/nevada/stories-in-nevada/solar-energy-at-former-mines/

_____ (n.d.) Solar Energy in the Mojave. Ensuring clean energy and habitat protection. Available at: https://www.nature.org/en-us/about-us/where-we-work/united-states/nevada/stories-in-nevada/mojave-desert-program/.

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Case study 32

Power of Place: how to integrate nature in energy planning

Location
For application in California, USA. Includes data from Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming

Mitigation hierarchy component
Avoidance/mitigation

Brief description of the project/initiative
California has ambitious climate and energy policies that call for the development of significant amounts of new renewable energy by mid-century. The Power of Place study conducted by The Nature Conservancy looks at multiple pathways to meet California's 100% zero-carbon electricity policy, while limiting the impacts of this energy development on high value natural and agricultural lands. To address this need, the study examined the environmental constraints and impacts of the new renewable energy development required to achieve California's goal of reducing greenhouse gas (GHG) emissions. Using detailed spatial datasets representing ecological, cultural and agricultural siting criteria in 11 western states, the study modelled onshore wind, solar and geothermal energy availability under four levels of environmental land protections. The study then used these wind, solar and geothermal energy estimates in a capacity expansion energy planning model, named RESOLVE, to build future electricity generation portfolios, assuming both no access and access to out-of-state renewable resources. The study shows that while many land areas across the West have high renewable resource potential and conservation values, with appropriate planning, there are multiple pathways to achieving this clean energy target while avoiding significant ecosystem impacts.

Reference
The Nature Conservancy (TNC) (2019). 'Power of Place Advancing a Clean Energy Future'. *TNC* [website], 5 August 2019. Available at: https://www.nature.org/en-us/about-us/where-we-work/united-states/california/stories-in-california/clean-energy/

Wu, G.C., Leslie, E., Sawyer, O., Cameron, D.R., Brand, E., Cohen, B., Allen, D., Ochoa, M. and Olson, A. (2020).Low-impact land use pathways to deep decarbonization of electricity. Environmental Research Letters 15 (7).

Aerial photos of the sunpower facility in Rosamond, California with wind farm in the background.
Photo: © Dave Lauridsen for The Nature Conservancy

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Case Study 33

The Crown Estate – Avoidance by sensitivity mapping

Location
UK

Mitigation hierarchy component
Avoidance

Brief description of the project/initiative
As managers of the seabed around England, Wales and Northern Ireland, The Crown Estate plays a fundamental role in the sustainable development of this national asset. This work includes helping to build the evidence base to reduce development risk and support the responsible expansion of the UK's world-leading offshore wind sector.

One example of this, is the extensive analysis undertaken by The Crown Estate to identify areas for offshore wind development under Offshore Wind Leasing Round 4. First, this considered the available technical resource (e.g. water depth) and the exclusion of "hard" constraints (e.g. IMO designated shipping routes) which preclude development. Next, activities and sensitivities considered "soft" constraints that wouldn't necessarily prohibit development but may increase development risk (e.g. environmental designations) were mapped. This spatial analysis was conducted in collaboration with and through input from a broad range of stakeholders. Following the principal analysis, a two-stage refinement process re-defined some of the regions identified.

During the refinement process, a review of current evidence and previous EIAs was commissioned to better understand potential ornithological constraints. Seabird density maps from the SeaMaST and NERC MERP projects were used to identify important areas for key species (e.g. red-throated diver and kittiwake). This was combined with information from Environmental Statements, consent decisions and post-consent monitoring to identify areas of greatest risk. Based on this evidence and stakeholder feedback, one region was removed and the boundary of one other was moved by 10-40 km to create buffer zones around Special Protection Areas. This removed the highest-risk areas from those offered for leasing. By the end of the process ten of the eighteen regions initially identified were excluded from those offered to market.

Four bidding areas were made available by The Crown Estate in September 2019. Within these, bidders have freedom to propose project sites (Figure 1). Following a three stage tender process, The Crown Estate will undertake a plan-level Habitats Regulations Assessment[504] to assess the impact of the proposed developments on nature conservation sites of European importance.

504 The stages of assessment required in accordance with the Conservation of Habitats and Species Regulations 2017 (UK) (as amended) and the Conservation of Offshore Marine Habitats and Species Regulations 2017 (UK) (as amended).

The four Seabed Bidding Areas are:

Bidding Area 1

Dogger Bank
Comprising the Dogger Bank region

Bidding Area 2

Eastern Regions
Comprising the Southern North Sea region, the eastern part of The Wash region, and the East Anglia region

Bidding Area 3

South East
Comprising the South East region

Bidding Area 4

Northern Wales & Irish Sea
Comprising the North Wales region, The Irish Sea region, and the northern part of the Anglesey region

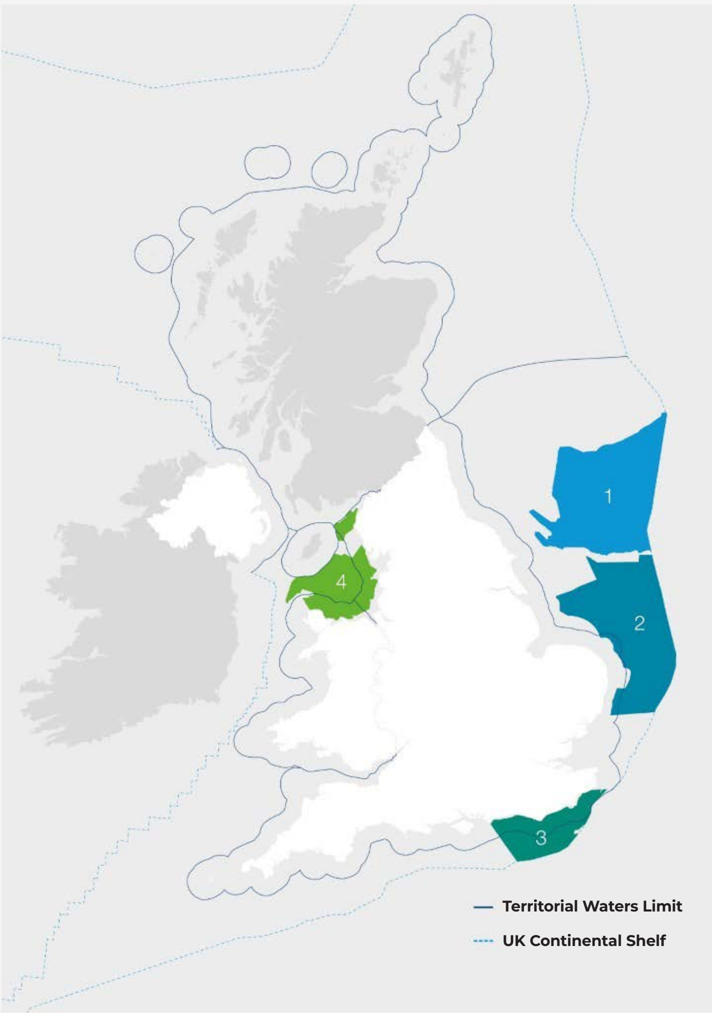

Figure 1. Offshore Wind Leasing Round 4 identified Bidding Areas (clockwise from top right) – 1. Dogger Bank, 2. Eastern Regions, 3. South East, and 4. Northern Wales and Irish Sea (Source: The Crown Estate, 2019).

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NUON
A2SEA

Annex 3.

List of species known to be sensitive to solar and wind developments

Onshore wind

Class	Species group	Species sub-group	Family (examples)	Species (examples)	Potential impacts	References to examples (not comprehensive)
Birds	Raptors	Large migratory eagles	Accipitridae	Steppe eagle (*Aquila nipalensis*)	Collision risk with turbines	Dixon et al. 2018. (https://www.conservationevidence.com/individual-study/6861); BirdLife International 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf)
		Large resident eagles		Verreaux's eagle (*Aquila verreauxii*)		Ralston Paton et al. 2017 (https://tethys.pnnl.gov/sites/default/files/publications/Ralston-Paton-et-al-2017.pdf)
				Martial eagle (*Polemaetus bellicosus*)		
				White-tailed eagle (*Haliaeetus albicilla*)		Dahl et al. 2013 (DOI: 10.1002/wsb.258); BirdLife international 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf)
		Old-world vultures		Rüppell's vulture (*Gyps rueppelli*)		TBC 2019 (https://www.thebiodiversityconsultancy.com/wp-content/uploads/2019/08/Wind-energy-TBC-IBN-August-2019-1.pdf); BirdLife international 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf)
				White-backed vulture (*Gyps africanus*)		
				Egyptian vulture (*Neophron percnopterus*)		Angelov et al. 2013 (doi:10.1017/S0959270912000123)
				Griffon vulture (*Gyps fulvus*)		De Lucas et al. 2012. (https://doi.org/10.1016/j.biocon.2011.12.029)
				Bearded vulture (*Gypaetus barbatus*)		Reid et al. 2015 (DOI: 10.1111/1365-2664.12468); Rushworth, I. and Krüger, S. 2013. Wind-farms threaten Southern Africa's cliff nesting vultures. Ezemvelo KZN Wildlife report, 23 pp. (unpublished)
				Cape vulture (*Gyps coprotheres*)		
				Black vulture (*Aegypius monachus*)		Dixon et al. 2018. (https://www.conservationevidence.com/individual-study/6861); BirdLife international 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf)
		Other migratory raptors		Black kite (*Milvus migrans*)		
				Common buzzard (*Buteo buteo*)		
				Long-legged buzzard (*Buteo rufinus*)		
				Common kestrel (*Falco tinnunculus*)		

Class	Species group	Species sub-group	Family (examples)	Species (examples)	Potential impacts	References to examples (not comprehensive)
Birds	**Raptors**	**Other migratory raptors**	**Falconidae**	Saker falcon (*Falco cherrug*)	Collision risk with turbines	Dixon et al. 2018. (https://www.conservationevidence.com/individual-study/6861); BirdLife international 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf)
				Amur falcon (*Falco amurensis*)		Ralston-Paton et al. 2017 (https://tethys.pnnl.gov/sites/default/files/publications/Ralston-Paton-et-al-2017.pdf)
			Accipitridae	White-tailed Hawk (*Buteo albicaudatus*)	Displacement	Villegas-Patraca et al. 2014 (https://doi.org/10.1371/journal.pone.0092462)
				Swainson's hawk (*Buteo swainsoni*)		
			Cathartidae	Turkey vulture (*Cathartes aura*)		
		Other resident raptors	**Accipitridae**	Jackal buzzard (*Buteo rufofuscus*)	Collision risk with turbines	Ralston Paton et al. 2017. (https://tethys.pnnl.gov/sites/default/files/publications/Ralston-Paton-et-al-2017.pdf); BirdLife South Africa, Johannesburg, South Africa
				Black harriers (*Circus maurus*)		
				Upland buzzard (*Buteo hemilasius*)		Dixon et al. 2018. (https://www.conservationevidence.com/individual-study/6861); BirdLife international 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf)
		Pelicans	**Pelecanidae**	Great white pelican (*Pelecanus onocrotalus*)		Thaxter et al. 2017 (https://doi.org/10.1098/rspb.2017.0829); BirdLife international 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf)
		Storks	**Ciconidae**	White stork (*Ciconia ciconia*)		
		Cranes	**Gruidae**	Blue crane (*Anthropoides paradiseus*)		Ralston-Paton et al., 2017 (https://tethys.pnnl.gov/sites/default/files/publications/Ralston-Paton-et-al-2017.pdf)
	Landfowl	**Spurfowl and francolins**	**Phasianidae**	Cape spurfowl (*Pternistis capensis*)		Ralston-Paton et al. 2017 (https://tethys.pnnl.gov/sites/default/files/publications/Ralston-Paton-et-al-2017.pdf); Jenkins et al. 2010 (http://www.the-eis.com/data/literature/Jenkins%20et%20al.%202010_Power%20line%20collisions%20review.pdf)

Class	Species group	Species sub-group	Family (examples)	Species (examples)	Potential impacts	References to examples (not comprehensive)
Bats	**Insectivores**		**Mormoopidae**	Davy's naked-backed bat (*Pteronotus davyi*)	Collision risk with turbines	Arnett et al. 2016 (https://doi.org/10.1007/978-3-319-25220-9)
				Ghost-faced bat (*Mormoops megalophylla*)		
			Vespertilionidae	Common pipistrelle (*Pipistrellus pipistrellus*)		Scottish Natural Heritage 2019 (https://www.nature.scot/sites/default/files/2019-01/Bats%20and%20onshore%20wind%20turbines%20-%20survey%2C%20assessment%20and%20mitigation.pdf); Arnett et al. 2016 ((https://doi.org/10.1007/978-3-319-25220-9)); Thaxter et al. 2017 (https://doi.org/10.1098/rspb.2017.0829)
				Soprano pipistrelle (*Pipistrellus pygmaeus*)		
				Common noctule (*Nyctalus noctula*)		
				Giant noctule (*Nyctalus lasiopterus*)		
				Chinese noctule (*Nyctalus plancyi velutinus*)		
				Leisler's bat (*Nyctalus leisleri*)		
				Nathusius' pipistrelle (*Pipistrellus nathusii*)		
				Hoary bat (*Lasiurus cinereus*)		Arnett et al. 2016 (https://doi.org/10.1007/978-3-319-25220-9); Thaxter et al. 2017 (https://doi.org/10.1098/rspb.2017.0829); Frick et al. 2017 (https://doi.org/10.1016/j.biocon.2017.02.023)
				Eastern red bat (*Lasiurus borealis*)		Arnett et al. 2016 (https://doi.org/10.1007/978-3-319-25220-9); Thaxter et al. 2017 (https://doi.org/10.1098/rspb.2017.0829)
				Silverhaired bat (*Lasionycteris noctivagans*)		
				Indiana bat (*Myotis sodalis*)		
				Hawaiian hoary bat (*Lasiurus cinereus semotus*)		
				Particolored bat (*Vespertilio murinus*)		
				Northern bat (*Eptesicus nilssonii*)		
				Kuhl's pipistrelle (*Pipistrellus kuhlii*)		
				Savi's pipistrelles (*Hypsugo savii*)		
				Leisler's bat (*Nyctalus leisleri*)		
				Cape serotine (*Neoromicia capensis*)		
				Gould's wattled bats (*Chalinolobus gouldii*)		
				Japanese pipistrelle (*Pipistrellus abramus*)		
				Horikawa's brown bat (*Eptesicus serotinus horikawai*)		
				Common house bat (*Scotophilus kuhlii*)		
				Taiwanese golden bat (*Myotis formosus flavus*)		
				Mouse-eared bat (*Myotis secundus*)		
				Japanese long-fingered bat (*Miniopterus fuliginosus*)		

Class	Species group	Species sub-group	Family (examples)	Species (examples)	Potential impacts	References to examples (not comprehensive)
Bats	Insectivores		Vespertilionidae	Yellow-necked sprite (*Arielulus torquatus*)	Collision risk with turbines	Arnett et al. 2016 (https://doi.org/10.1007/978-3-319-25220-9); Thaxter et al. 2017 (https://doi.org/10.1098/rspb.2017.0829)
				Taiwanese tube-nosed bat (*Murina puta*)		
			Molossidae	East Asian free-tailed bat (*Tadarida insignis*)		
				Brazilian free-tailed bats (*Tadarida brasiliensis*)		
				Egyptian free-tailed bat (*Tadarida aegyptiaca*)		
				White-striped free-tailed bat (*Austronomus australis*)		
			Emballonuridae	none specified		Ng et al. 2019 Challenges to mitigating wind energy impacts on bats in the tropics and sub-tropics. Conference of Wind and Wildlife Impacts. 27-30 August 2019
			Miniopteridae	none specified		
			Craseonycteridae	none specified		
			Cistugidae	none specified		
			Rhinopomatidae	none specified		
	Fruit bats		Pteropodidae	Wahlberg's epauletted fruit bat (*Epomophorus wahlbergi*)		MacEwan 2016 (http://www.africanbats.org/Documents/Papers/MacEwan_2016.pdf); Ng et al. 2019 Challenges to mitigating wind energy impacts on bats in the tropics and sub-tropics. Conference of Wind and Wildlife Impacts. 27-30 August 2019; Thaxter et al. 2017 (https://doi.org/10.1098/rspb.2017.0829)
				Egyptian Rousette (*Rousettus aegyptiacus*)		

Offshore wind

Class	Species group	Species sub-group	Family (example)	Species (example)	Potential impacts	References to examples (not comprehensive)
Marine megafauna (mammals, sharks & rays and sea turtles)	**Cetaceans**	**Whales**	**Monodontidae**	Should apply to all as a precautionary approach	Vessel strike; Injury/behavioural effects of underwater noise (e.g. vessels, piling, maintenance); Barrier or displacement effect	Normandeau Associates, Inc. 2012 (https://www.cbd.int/doc/meetings/mar/mcbem-2014-01/other/mcbem-2014-01-submission-boem-04-en.pdf); Sparling et al. 2017 (http://data.jncc.gov.uk/data/e47f17ec-30b0-4606-a774-cdcd90097e28/JNCC-Report-607-FINAL-WEB.pdf); Riefolo et al., 2016 (https://www.onepetro.org/conference-paper/ISOPE-I-16-317); Thomsen et al. 2006 (https://tethys.pnnl.gov/sites/default/files/publications/Effects_of_offshore_wind_farm_noise_on_marine-mammals_and_fish-1-.pdf)
			Balaenidae			
			Cetotheriidae			
		Dolphins	**Delphinidae**			
		Porpoises	**Phocoenidae**	Harbour porpoise (*Phocoena phocoena*). Should apply to all as a precautionary approach		
	Pinnipeds	**True seals**	**Phocoidea**	Harbour seals (*Phoca vitulina*). Should apply to all as a precautionary approach	Vessel strike; Injury/behavioural effects of underwater noise (e.g. vessels, piling, maintenance); Displacement effect	Sparling et al. 2017 (http://data.jncc.gov.uk/data/e47f17ec-30b0-4606-a774-cdcd90097e28/JNCC-Report-607-FINAL-WEB.pdf); Hastie et al. 2015 (https://doi.org/10.1111/1365-2664.12403); Hastie et al. 2019 (https://doi.org/10.1002/eap.1906); Riefolo et al., 2016 (https://www.onepetro.org/conference-paper/ISOPE-I-16-317); Thomsen et al. 2006 (https://tethys.pnnl.gov/sites/default/files/publications/Effects_of_offshore_wind_farm_noise_on_marine-mammals_and_fish-1-.pdf)
		Walruses and fur seals	**Otarioidea**	Should apply to all as a precautionary approach		
	Sirenians	**Dugongs**	**Dugongidae**	Should apply to all as a precautionary approach	Vessel strike; Injury/behavioural effects of underwater noise (e.g. vessels, piling, maintenance); Displacement effect	Sparling et al. 2017 (http://data.jncc.gov.uk/data/e47f17ec-30b0-4606-a774-cdcd90097e28/JNCC-Report-607-FINAL-WEB.pdf); Hastie et al. 2015 (https://doi.org/10.1111/1365-2664.12403); Hastie et al. 2019 (https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1002/eap.1906); Riefolo et al. 2016 (https://www.onepetro.org/conference-paper/ISOPE-I-16-317)
		Manatees	**Trichechidae**			
	Sea turtles		**Chelonioidea**	Should apply to all as a precautionary approach	Vessel strike; Injury/behavioural effects of underwater noise (e.g. vessels, piling, maintenance), Barrier or displacement effect	Normandeau Associates, Inc. 2012 (https://www.cbd.int/doc/meetings/mar/mcbem-2014-01/other/mcbem-2014-01-submission-boem-04-en.pdf); Riefolo et al., 2016 (https://www.onepetro.org/conference-paper/ISOPE-I-16-317); Dow Piniak et al. 2012 (https://www.semanticscholar.org/paper/Underwater-hearing-sensitivity-of-the-leatherback-(-Piniak-Eckert/3ec87364f6a6dfc28ebf4d733a8fec7c68ce9e61)
	Elasmobranchs		**Varied**	Could apply to all coastal species as a precautionary approach	Behavioural effects of electromagnetic fields associated with wind farm cables	Normandeau Associates, Inc. 2012 (https://www.cbd.int/doc/meetings/mar/mcbem-2014-01/other/mcbem-2014-01-submission-boem-04-en.pdf); Riefolo et al., 2016 (https://www.onepetro.org/conference-paper/ISOPE-I-16-317)
Fish	**Fish with a swim bladder**		**Varied**	Atlantic salmon (*Salmo salar*), Atlantic cod (*Gadus morhua*), Atlantic herring (*Clupea harengus*)	Injury/behavioural effects of underwater noise (e.g. vessels, piling, maintenance)	Normandeau Associates, Inc. 2012 (https://www.cbd.int/doc/meetings/mar/mcbem-2014-01/other/mcbem-2014-01-submission-boem-04-en.pdf); Weilgart 2018 (https://www.oceancare.org/wp-content/uploads/2017/10/OceanNoise_FishInvertebrates_May2018.pdf); Thomsen et al. 2006 (https://tethys.pnnl.gov/sites/default/files/publications/Effects_of_offshore_wind_farm_noise_on_marine-mammals_and_fish-1-.pdf)
	Fish without a swim bladder		**Varied**	Dab (*Limanda limanda*)	Injury/behavioural effects of underwater noise (e.g. vessels, piling, maintenance)	Thomsen et al. 2006 (https://tethys.pnnl.gov/sites/default/files/publications/Effects_of_offshore_wind_farm_noise_on_marine-mammals_and_fish-1-.pdf)
	Vocal' fish		**Varied**	Salmonid species (*Salmo, Salvelinus and Oncorhynchus*)	Injury/behavioural effects of underwater noise (e.g. vessels, piling, maintenance)	Normandeau Associates, Inc. 2012 (https://www.cbd.int/doc/meetings/mar/mcbem-2014-01/other/mcbem-2014-01-submission-boem-04-en.pdf); Weilgart 2018 (https://www.oceancare.org/wp-content/uploads/2017/10/OceanNoise_FishInvertebrates_May2018.pdf)

Class	Species group	Species sub-group	Family (example)	Species (example)	Potential impacts	References to examples (not comprehensive)
Birds	**Seabirds**	**Duck**	**Anatidae**	Greater scaup (*Aythya marila*)	Collision risk with turbines; Barrier or displacement effect	Humphreys et al. 2015 (https://www.bto.org/sites/default/files/shared_documents/publications/research-reports/2015/rr669.pdf); Goodale et al. 2019 (https://doi.org/10.1088/1748-9326/ab205b)
				Common eider (*Somateria mollissima*)		
				Long-tailed duck (*Clangula hyemalis*)		
				Common scoter (*Melanitta nigra*)		
				Velvet scoter (*Melanitta fusca*)		
				Common goldeneye (*Bucephala clangula*)		
				Red-breasted merganser (*Mergus serrator*)		
		Migratory aquatic bird	**Gaviidae**	Red-throated diver (*Gavia stellata*)		
				Black-throated diver (*Gavia arctica*)		
				Great northern diver (*Gavia immer*)		
			Hydrobatidae	European storm-petrel (*Hydrobates pelagicus*)		
			Hydrobatidae	Leach's storm-petrel (*Oceanodroma leucorhoa*)		
			Phalacrocoracidae	Great cormorant (*Phalacrocorax carbo*)		
			Alcidae	Black guillemot (*Cepphus grylle*)		
			Sulidae	northern gannet (*Morus bassanus*)	Collision risk with turbines	Furness et al. 2013 (10.1016/j.jenvman.2013.01.025)
			Scolopacidae	Red-necked phalarope (*Phalaropus lobatus*)	Collision risk with turbines; Barrier or displacement effect	Bradbury et al. 2014 (doi:10.1371/journal.pone.0106366)
		Auk	**Alcidae**	Common guillemot (*Uria aalge*)		Humphreys et al. 2015 (https://www.bto.org/sites/default/files/shared_documents/publications/research-reports/2015/rr669.pdf); Goodale et al. 2019 (https://doi.org/10.1088/1748-9326/ab205b)
			Alcidae	Little auk (*Alle alle*)		
				Razorbill (*Alca torda*)		
				Atlantic puffin (*Fratercula arctica*)		
		Shearwaters	**Procellariidae**	Balearic shearwater (*Puffinus mauretanicus*)		
				Manx shearwater (*Puffinus puffinus*)		
			Phalacrocoracidae	Common shag (*Phalacrocorax aristotelis*)		
			Procellariidae	Northern fulmar (*Fulmarus glacialis*)		
	Raptors	**Large resident eagles**	**Accipitridae**	White-tailed eagle (*Haliaeetus albicilla*)	Collision risk with turbines; Barrier or displacement effect	Dahl et al. 2013 (DOI: 10.1002/wsb.258); BirdLife international 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf)

Class	Species group	Species sub-group	Family (example)	Species (example)	Potential impacts	References to examples (not comprehensive)
Birds	**Raptors**	**New world vultures**	**Cathartidae**	Turkey vulture (*Cathartes aura*)	Collision risk with turbines; Barrier or displacement effect	Villegas-Patraca et al. 2014 (https://doi.org/10.1371/journal.pone.0092462)
		Other migratory raptors	**Accipitridae**	White-tailed Hawk (*Buteo albicaudatus*)		
				Swainson's hawk (*Buteo swainsoni*)		
	Gulls and relatives		**Laridae**	European herring gull (*Larus argentatus*)		Furness et al. 2013 (DOI: 10.1016/j.jenvman.2013.01.025); Thaxter et al. 2017 (https://doi.org/10.1098/rspb.2017.0829); BirdLife international 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf); Bradbury et al. 2014 (doi:10.1371/journal.pone.0106366)
				Great black-backed gull (*Larus marinus*)		Furness et al. 2013 (DOI: 10.1016/j.jenvman.2013.01.025); Bradbury et al. 2014 (doi:10.1371/journal.pone.0106366)
				Lesser black-backed gull (*Larus fuscus*)		
				Mediterranean gull (*Ichthyaetus melanocephalus*)		Bradbury et al. 2014 (doi:10.1371/journal.pone.0106366)
				Black-legged kittiwake (*Rissa tridactyla*)		
				Common gull (*Larus canus*)		
				Glaucous gull (*Larus hyperboreus*)		
				Iceland gull (*Larus glaucoides*)		
			Sulidae	Northern gannet (*Morus bassanus*)		
	Shorebirds	**Waders**	**Scolopacidae**	Great Knot (*Calidris tenuirostris*)	Collision risk with turbines	Thaxter et al. 2017 (https://doi.org/10.1098/rspb.2017.0829)
Bats	**Insectivorous bats**		**Vespertilionidae**	Daubenton's bat (*Myotis daubentoni*)		Ahlén et al. 2007 (https://www.naturvardsverket.se/Documents/publikationer/620-5571-2.pdf); Lagerveld et al. 2017 (https://library.wur.nl/WebQuery/wurpubs/fulltext/417091)
				Common noctule (*Nyctalus noctula*)		
				Lesser noctule (*Nyctalus leisleri*)		
				Common pipistrelle (*Pipistrellus pipistrellus*)		
				Nathusius' pipistrelle (*Pipistrellus nathusii*)		
				Soprano pipistrelle (*Pipistrellus pygmaeus*)		
				Serotine bat (*Eptesicus serotinus*)		
				Northern bat (*Eptesicus nilssonii*)		Ahlén et al. 2007 (https://www.naturvardsverket.se/Documents/publikationer/620-5571-2.pdf)
				Parti-coloured bat (*Vespertilio murinus*)		
				Pond bat (*Myotis dasycneme*)		
				Big brown bat (*Eptesicus fuscus*)		Pelletier et al. 2013 (https://tethys.pnnl.gov/sites/default/files/publications/BOEM_Bat_Wind_2013.pdf); Peterson 2016 (https://www.osti.gov/servlets/purl/1238337)
				Silver-haired bat (*Lasionycteris noctivagans*)		
				Eastern red bat (*Lasiurus borealis*)		
				Tricolored bat (*Perimyotis subflavus*)		
				Hoary bat (*Lasiurus cinereus*)		

Solar

Class	Species group	Potential impacts	References to examples (not comprehensive)
Birds	Various groups (insufficient evidence to show which are more at risk)	Collision with solar panels and associated infrastructure	Kagan et al. 2014.(DOI: 10.1016/j.renene.2016.02.041)
		Poisoning and drowning	Jeal et al. 2019. (DOI 10.2989/00306525.2019.1581296)
	Migratory soaring birds (raptors, storks, pelicans, cranes)	Barrier effect, singeing, collision	BirdLife international 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf); Ho et al. 2016 (DOI: 10.1063/1.4949164)

Transmission lines

Class	Species group	Species sub-group	Family (examples)	Species (examples)	Potential impacts	References to examples (not comprehensive)
Birds	**Large waterbirds**	**Ducks and geese**	**Anseridae**	Spur-winged goose (*Plectropterus gambensi*)	Collison risk with transmission lines	Shaw et al. 2010 (https://doi.org/10.2989/00306525.2010.488421)
		Flamingos	**Phoenicopteridae**	Greater flamingo (*Phoenicopterus roseus*)		van Rooyen et al. 2017 (https://sahris.sahra.org.za/sites/default/files/additionaldocs/Gamma%20Kappa%20Bird%20Impact%20Assessment%20Revised%20Report_240817%20(3).pdf)
				Lesser flamingo (*Phoeniconaias minor*)		
		Storks	**Ciconidae**	White stork (*Ciconia ciconia)*		Thaxter et al. 2017 (https://royalsocietypublishing.org/doi/pdf/10.1098/rspb.2017.0829); BirdLife international 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf)
	Large terrestrial birds	**Bustards**	**Otididae**	Bengal florican (*Houbaropsis bengalensis*)		Mahood et al. 2017 (doi:10.1017/S0030605316000739)
				Ludwig’s bustard (*Neotis ludwigii*)		Shaw et al. 2010 (https://doi.org/10.2989/00306525.2010.488421)
				Great bustard (*Otis tarda*)		Raab et al. 2012 (DOI: https://doi.org/10.1017/S0959270911000463)
				Denhams bustard (*Neotis denhami*)		Shaw et al. 2010 (https://doi.org/10.2989/00306525.2010.488421)
		Cranes	**Gruidae**	Blue crane (*Anthropoides paradiseus*)		Ralston-Paton et al. 2017 (https://tethys.pnnl.gov/sites/default/files/publications/Ralston-Paton-et-al-2017.pdf)
		Ground hornbills	**Bucorvidae**	Southern ground hornbill (*Bucorvus leadbeateri*)		Thaxter et al. 2017 (https://royalsocietypublishing.org/doi/pdf/10.1098/rspb.2017.0829); BirdLife international 2012 (http://migratorysoaringbirds.undp.birdlife.org/sites/default/files/factsheet%20Solar%20Developer%20v1H.pdf)
	Gamebirds	**Spurfowl and francolins**	**Phasianidae**	Cape spurfowl (*Pternistis capensis*)		Ralston-Paton et al. 2017 (https://tethys.pnnl.gov/sites/default/files/publications/Ralston-Paton-et-al-2017.pdf); Jenkins et al. 2010 (doi:10.1017/S0959270910000122)

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