Opportunities for enhancing biodiversity at wind and solar energy developments

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INTERNATIONAL UNION FOR CONSERVATION OF NATURE

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Acronyms

AMCP	Arkansas Monarch Conservation Partnership
CSRD	Corporate Sustainability Reporting Directive
ESRS	European Sustainability Reporting Standards
EU	European Union
KMGBF	Kunming-Montreal Global Biodiversity Framework
GHG	Greenhouse gas
GRI	Global Reporting Initiative
Ha	Hectare
IUCN	International Union for Conservation of Nature
KBA	Key Biodiversity Area
MH	Mitigation Hierarchy
MW	Megawatt
NbS	Nature-based Solutions
NG	Net Gain
NGO	Non-governmental organisation
NNL	No Net Loss
NPI	Net Positive Impact
NTZ	No-trawling zone
OWF	Offshore wind farm
PHASE	Pollinator Habitat Aligned with Solar Energy
PV	Photovoltaic
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SDG	Sustainable Development Goal
SPA	Special Protection Area
SPIES (DST)	Solar Park Impacts on Ecosystem Services (decision support tool)
STAR	Species Threat Abatement and Restoration (Metric)
TBC	The Biodiversity Consultancy
TES	Techno-ecological synergy
TNC	The Nature Conservancy
TNFD	Taskforce on Nature-related Financial Disclosures
WDKBA	World Database of Key Biodiversity Areas
WDPA	World Database on Protected Areas
WECAT	Wind Energy Condor Action Team

Glossary

Agrivoltaics	Pairing solar energy generation with agriculture
Additional conservation actions	Measures taken that have positive, but difficult to quantify, effects on biodiversity
Conservoltaics	Pairing solar energy generation with biodiversity conservation
Ecosystem services	The benefits that people derive from ecosystems. Categorised into provisioning services (e.g. food, water, medicine), regulation services (e.g. climate regulation, flood control), cultural services (e.g. recreation), and supporting services (e.g. nutrient cycling, habitat provision).
Ecovoltaics	Pairing solar energy generation with biodiversity conservation and the delivery of ecosystem services
Floatovoltaics	Solar photovoltaic system installation over water bodies, such as canals or reservoirs
Kunming-Montreal Global Biodiversity Framework (KMGBF)	Adopted during COP 15 and sets out a suite of goals and targets for overall biodiversity outcomes by 2030 and 2050
Hibernaculum	The place in which an animal seeks refuge – can be natural or artificial in the case of the provision of additional shelter for bats
Microclimate	A fine-scale climate variation that deviates from the background atmosphere, at least temporarily (Pincebourde & Woods, 2020)
Microhabitat	A localised and small scale environment that supports a distinct flora and fauna (Shi et al., 2016)
Mitigation hierarchy	The sequence of actions to anticipate and avoid impacts on biodiversity and ecosystem services; and where avoidance is not possible, minimise; and, when impacts occur, rehabilitate or restore; and where significant residual impacts remain, offset (CSBI & TBC, 2015).
Nature positive	There is no single agreed definition – several are in use. The Nature Positive Initiative defines it as 'halt and reverse nature loss by 2030 on a 2020 baseline and achieve full recovery by 2050.' According to the UK Council for Sustainable Business, "a nature-positive approach… goes beyond reducing and mitigating negative impacts on nature as it is a proactive and restorative approach focused on conservation, regeneration, and growth" (zu Ermgassen et al., 2022, p. 3).
Nature-based Solutions	Actions to address societal challenges through the protection, sustainable management and restoration of ecosystems, benefiting both biodiversity and human well-being through the services they provide (IUCN, 2020).
No Net Loss	The point at which adverse impacts on biodiversity are balanced by measures taken through the application of the mitigation hierarchy, so that no losses remain
Net Positive Impact	The point at which adverse impacts on biodiversity are outweighed by measurable outcomes from actions taken in accordance with the mitigation hierarchy to achieve sustainable biodiversity gains.
Sward	An established expanse of grasses, legumes and other species which are close-growing and form a dense stand that covers the ground.

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1 Introduction

1.1 The renewable energy transition

The need to transition to a lower carbon, nature-safe renewable energy-based economy is more urgent than ever (WWF & BCG, 2023; WWF & TBC, 2023). The Paris Agreement sets a stringent target of limiting global warming to 2°C above pre-industrial levels by 2050,[1] thus emphasising the necessity of urgent, rapid, and extensive renewable energy adoption to achieve this goal. Delays in implementing low carbon energy solutions as part of the transition from fossil fuels to renewable energy will severely hinder progress towards this goal.

In parallel, the recently adopted Kunming-Montreal Global Biodiversity Framework (KMGBF) has the overall vision of achieving full recovery of nature by 2050. KMGBF aims to halt and reverse biodiversity loss by 2030, to sustain a healthy planet, whilst delivering benefits essential for human well-being and economic prosperity for all people.

Global climate and nature goals highlight that the transition to low-carbon energy cannot occur in isolation, nor in a vacuum – achieving them both requires combining efforts to reduce greenhouse gas (GHG) emissions with biodiversity conservation and ensuring they are mutually beneficial (action on climate is not necessarily inherently good for biodiversity (Dunne, 2022). Furthermore, lack of access to energy remains a critical challenge in many countries, subjecting many people to a life of poverty. In 2023, at the halfway point for achieving the 2030 Sustainable Development Goals (SDGs), the world was not on track to achieve SDG 7. Addressing this challenge, therefore, through the rapid deployment of renewable energy is paramount to ensuring access to affordable, reliable, sustainable, and modern energy for all (IEA, 2023; IAE et al., 2023; Roser, 2020). All of this implies the need to transform the way societies are operating to address the current biodiversity and ecosystem collapse and work towards a just and nature positive future.[2] However, whilst large-scale decarbonisation of global power infrastructure is essential to meeting climate goals, it must not happen at the expense of nature (Gasparatos et al., 2017; TNC, 2021) – especially as this would likely reduce the efficacy of decarbonisation efforts.

1.2 Purpose of this document

Well planned solar and wind energy developments have the potential to enhance the condition of habitats and associated biodiversity and increase carbon sequestration, beyond the mitigation or project-related impacts. Thus, the concept of biodiversity enhancement has gained increasing recognition in recent years as a means for the renewable energy sector to contribute to these broader positive outcomes.

This document provides an overview of potential opportunities for biodiversity enhancement for wind and solar developments, bringing together information on good practice principles, case studies from industry practice, and a summary of existing approaches to biodiversity enhancement. It is intended as a compendium summary resource for developers, combining a variety of diffuse information from literature and community of practice. The examples included are indicative of opportunity and potential. They are not exhaustive, nor are they intended as recommendations (robust context-specific assessment and feasibility study is always required to identify appropriate actions). Neither is this document intended to inform future regulations or requirements. Above all, this resource is designed to encourage ideas and progress in a rapidly advancing field of biodiversity management.

1 To achieve the Paris Agreement goal, greenhouse gas (GHG) emissions must peak before 2025 at the latest and decline 43% by 2030. However, global GHG emissions continue to increase, for various reasons (IPCC, 2023a).

2 Note that the KMGBF does not specifically include the term 'nature positive', and there is no single agreed definition for this concept. Although several are in use (e.g. see zu Ermgassen et al., 2022). IUCN is developing a quantitative methodology to help companies, governments and civil society assess opportunities and risks, set targets, measure progress, and deliver nature-positive impacts (IUCN, 2022).

1.3 The context for biodiversity enhancement

1.3.1 Biodiversity enhancement and the mitigation hierarchy

Many renewable energy developers are now setting project level goals for biodiversity, which may depend on the requirements and views of regulators, financiers, and stakeholders (Bennun et al., 2021). Typically, these goals are for measurable NNL or NPI (also referred to as Net Gain), met through the rigorous application of the mitigation hierarchy. The mitigation hierarchy is a well-established sequential and iterative set of four actions to address the negative impacts of developments on biodiversity: avoid, minimise, restore, and offset (Bennun et al., 2021; CSBI & TBC, 2015).

Biodiversity enhancement is **additional to the mitigation hierarchy.** It has been defined as 'genuine improvement of the natural heritage interest of a site or area through better management, or the addition of new or better habitats or features than currently present' (Rajvanshi et al., 2011, p. 182). It represents conservation actions that can be taken to further benefit biodiversity, beyond those gains required to meet NNL or NPI objectives directly linked to project impacts. Thus, by definition, enhancement contributes to the sum of biodiversity gains delivered by a project. This means that when NNL has been achieved through the mitigation hierarchy, and provided that there are no obligations to achieve a specified quantity of gain with respect to project impacts (e.g. legislation requiring offsetting or compensation), enhancement actions contribute to net gains. Enhancement actions can also contribute to gains under voluntary NPI commitments, depending on how the voluntary commitment is defined.

Enhancement actions are usually taken at the project level (i.e. within the boundaries of a solar or wind farm) to restore or create natural or semi-natural habitats and/or to benefit key target species. Biodiversity enhancement measures need not necessarily target the same features directly or indirectly impacted by a project (i.e. the features to which NNL/NPI targets relate), although ideally, enhancement should still focus on components of biodiversity that are connected to the project – that is, directly linked to, associated with, or affected by a particular project (Rajvanshi et al., 2011). In other words, enhancement actions should target features present in the project area and surrounding landscape or seascape context, whether they are directly or indirectly impacted by a project.

When planning, enhancement measures should be considered separately from actions to address the direct, indirect, and cumulative impacts of development. Once projects have implemented actions in line with the mitigation hierarchy designed to deliver NNL or NPI, enhancement measures are the 'extras' that could be delivered to increase biodiversity gains and contribute further to the global goal of halting and reversing biodiversity loss. This will require careful consideration, since the actions involved may be similar. In some cases, the same action can support both mitigation and then further enhancement outcomes (see Table 1), and in other cases they may conflict with impact mitigation.

For example:

- Measures in line with the mitigation hierarchy will be required to achieve NPI for a wind farm with residual collision impacts on raptors. At the same wind farm project site, creation of wildflower meadows for pollinators could constitute a biodiversity enhancement measure that is not related to the residual impact of the wind farm.

- Conversely, enhancing the habitat within the wind farm might not be appropriate because it could result in making the site more attractive to those at-risk birds or bats (e.g. Roeleke et al., 2016).

Hence, in most cases, developers should prioritise on-site enhancement, but there may be some instances where measures beyond the project site are more appropriate. Effective enhancement requires a good understanding of the biodiversity baseline, including the species and habitats that are, or were, present, and the ecosystem services delivered at the project site and surroundings. To be able to demonstrate positive outcomes for the intended biodiversity features, both project impact mitigation measures and biodiversity enhancement measures should be monitored in relation to this baseline.

Biodiversity enhancement measures are also different to additional conservation actions, which themselves fall outside the mitigation hierarchy. Additional conservation actions are difficult to quantify because they are often not in situ or direct measures on the ground, and instead are supporting, enabling, and awareness-raising actions like educational campaigns, novel research and development, or policy changes. Enhancement actions, on the other hand, directly address the state or condition of a biodiversity feature on the ground, are measurable, and often similar or same actions as those designed to mitigate impacts (see Figure 1 and Table 1).

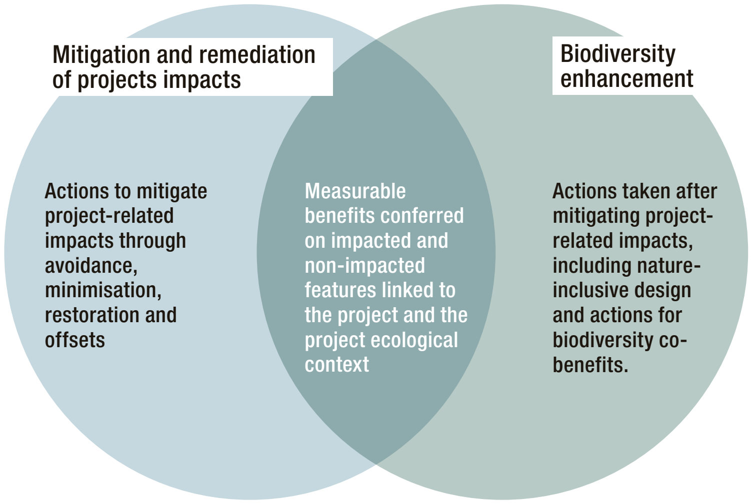

Figure 1 Biodiversity enhancement vs other actions to mitigate and remediate impacts on biodiversity *Source: Authors.*

Table 1 An illustration of mitigation hierarchy actions vs biodiversity enhancement actions for an onshore wind farm

MITIGATION OF PROJECT-RELATED IMPACTS		BIODIVERSITY ENHANCEMENT	
MITIGATION MEASURE	**OUTCOME**	**ENHANCEMENT MEASURE**	**OUTCOME**
Avoidance by design: designing project layout and configuration to avoid specific high value habitat within a project boundary	Reduced residual direct footprint impact on specific high value habitat	On-going restoration and protection of these avoided high value habitat areas to improve condition and biodiversity value	Contributes to positive biodiversity outcomes for a habitat associated with the project site, after action in line with the mitigation hierarchy to address project-related impact
Restoration of on-site habitat areas temporarily disturbed by construction activities	Reduces project's residual adverse impacts on biodiversity	**Restoration** of habitat within the site perimeter that has not been impacted by project activities but has been degraded by previous activities on the land (e.g. agriculture)	Contributes to positive biodiversity outcomes for a habitat associated with the project site
Restoring natural habitat beyond the site boundary to encourage species at risk of project impacts away from the site	Reduces project's residual adverse impacts on biodiversity	Same action contributes to positive biodiversity outcomes for a biodiversity linked to/associated with the project, but not impacted by the project	
Offsetting the physical loss of habitat cleared for project infrastructure through on-going restoration offsets and protection of areas of the same habitat type that are at risk of future loss elsewhere, on or off site (averted loss)	Compensating for project's residual adverse impacts on biodiversity	Restoration and averted loss actions beyond the project site boundary but within the same ecological context, for features not impacted by the project, or for which NNL/NPI has been achieved via the mitigation hierarchy	Contributes to positive biodiversity outcomes for features associated with the project site, after action in line with the mitigation hierarchy to address project-related impact

Source: Authors.

Opportunities for biodiversity enhancement vary according to the state of biodiversity at the project site. A development in a degraded area, such as unproductive agricultural land, is likely to provide greater opportunities for biodiversity enhancement than more intact landscapes, such as natural habitats.[3] Enhancement is focused on biodiversity, but can often create additional benefits through improving provision of ecosystem services (Section 1.3.2). Examples of biodiversity enhancement include nature-inclusive design features that are selected to provide additional conservation benefits rather than to mitigate for project impacts.

In summary, biodiversity enhancement can be defined as (Figure 1):

- Conservation actions, usually taken at the project-level, that measurably improve biodiversity after, and additional to actions taken in line with the mitigation hierarchy.

1.3.2 Enhancement, ecosystem services, and nature-based solutions

The definition of ecosystems considers both organisms and the environments within which they occur (Tansley, 1935). With increasing recognition of the importance of ecosystem services (the benefits that ecosystems provide to people (Neugarten et al,. 2018), the concept of nature-based solutions (NbS) has developed. NbS are actions to address societal challenges through the protection, sustainable management and restoration of ecosystems, benefiting both biodiversity and human well-being through the services they provide (IUCN, 2020). Ecosystem services are typically categorised into four groups:

1) Provisioning services: products obtained from ecosystems (e.g. food, fresh water, medicinal resources);

2) Regulating services: benefits obtained from the regulation of ecosystem processes (e.g. climate regulation, flood control, disease regulation);

3) Cultural services: non-material benefits people obtain from ecosystems (e.g. recreation, spiritual benefits); and

4) Supporting services: services that are necessary for the production and maintenance of all other ecosystem functions (e.g. nutrient cycling, habitat provision).

Biodiversity enhancement measures in wind and solar projects may often also constitute NbS, since actions that enhance ecosystem services can also address key societal challenges,[4] Examples include: mitigating climate change through carbon sequestration; contributing to human health through enhancing ecosystem intactness; increasing food security through enhancing pollination services; increasing water security through restoration of riparian habitats; preventing natural disasters through the enhancement of habitats' ability to withstand landslides or floods, and countering biodiversity loss itself.[5] Properly managed efforts to enhance biodiversity both in terms of actions related to natural or semi-natural habitats, as well as species, will inherently strengthen the resilience of ecosystem and their capacity to deliver services essential to people.

Recognising the importance of biodiversity enhancement to the provision of NbS, the TRANSEATION project funded by the European Union's Horizon Europe innovation programme highlights the important role 'blue-grey infrastructure', such as offshore wind farms, can play in protecting and restoring the health of our marine ecosystems through enhancing nature-based solutions. Similarly, the Pollinator Habitat Aligned with Solar Energy project (PHASE) in the United States aims to investigate the ecological and economic benefits as well as performance impacts of co-located pollinator plantings at large, utility-scale photovoltaic (PV) facilities in more detail. Onshore, the potential for enhancing natural vegetation to provide pollination services for surrounding agricultural areas has been widely recognised (Armstrong et al., 2021; Semeraro

3 Examples of terrestrial natural habitats are mapped through the SBTN Natural Lands Map 2020 v1
4 Semeraro et al. (2020) present a conceptual framework for designing green infrastructure looking at solar PV systems in synergy with ecosystem services. A case study from Italy shows the framework increases solar energy production and improves/increase several ecosystem services.
5 https://iucn.org/our-work/nature-based-solutions

et al., 2018; Walston et al., 2018, 2021, 2023; Wit & Biesmeijer, 2020).

Biodiversity enhancements may also provide direct management benefits for renewable energy projects, by improving efficiency and reducing maintenance costs and impacts. Some examples include:

- The use of nature-inclusive design for scour protection at offshore wind farms to create reef substrate and reduce the negative impacts of scouring (Lengkeek et al., 2017).
- Restoration of natural vegetation to moderate run-off and erosion damage in areas subject to intense seasonal rainfall, reducing costs for maintenance of access roads and onshore turbine foundations.
- Restoration of native vegetation, improving the efficiency of solar panels by reducing the temperature beneath them, and also acts to stabilise the soil, reducing dust, and therefore the amount of water needed to keep solar panels dust free and functioning optimally (Al-Dousari et al., 2020; Chemisana & Lamnatou, 2014; Macknick et al., 2013).

1.3.3 Biodiversity enhancement and the mitigation hierarchy

In parallel with the KMGBF (see Section 1.1), the 'nature positive' concept has emerged as an inclusive and ambitious 'rallying call' that aligns with the KMGBF (Booth et al., 2024). 'Nature' is often used as a shorthand for biodiversity, but it is a broader concept that also encompasses non-living components, such as climate, air, soil, and water. Conservation and business forums are increasingly converging on the concept of nature positive (zu Ermgassen et al., 2022) to achieve the 2030 and 2050 goals of the KMGBF, and drive transformative change in the relationship between business and nature. There is no single agreed definition of the term, and several are in use. In line with the KMGBF, the Nature Positive Initiative defines it as "halt and reverse nature loss by 2030 on a 2020 baseline and achieve full recovery by 2050" (Nature Positive Initiative, 2023). The UK Council for Sustainable Business defines the concept as "a nature-positive approach [that] puts nature and biodiversity gain at the heart of decision-making and design. It goes beyond reducing and mitigating negative impacts on nature as it is a proactive and restorative approach focused on conservation, regeneration, and growth" (zu Ermgassen et al., 2022, p. 3). Debate continues on what 'nature positive' means for business (Milner-Gulland, 2022; zu Ermgassen et al., 2022), where it is generally viewed as a broad societal goal to which businesses and civil society can contribute, rather than a specific project or organisational-level objective (Booth et al., 2024).

The idea of nature positive emerges from the urgent need to conserve and restore nature – with widespread recognition of the pace at which species and ecosystems are disappearing and the scale of risk this poses to business and society (see Dasgupta, 2021; IPBES ,2022; WWF, 2022). Nature positive moves beyond traditional corporate approaches, such as NNL or NPI of biodiversity in three main ways (TBC, 2022): i) a broader scope, encompassing all of a company's value chain and integrating all of nature; ii) clearer alignment with global goals – requiring absolute improvements in the state of nature, not just slowing down its loss; and iii) emphasis on both mainstreaming nature in corporate structures and processes, and broader, transformational systems change that goes beyond any single company.

Application of the mitigation hierarchy is central to a nature positive approach (Maron et al., 2023; White et al., 2024). This means strongly prioritising impact avoidance and minimisation, whether at project, landscape or systems levels. To meet the GBF and nature positive goals for nature recovery, further conservation actions will also then be needed to obtain an overall net gain of biodiversity. As such, biodiversity enhancement is entirely aligned with a nature positive approach – providing that it is additional to, not an alternative to, application of the mitigation hierarchy (Maron et al., 2023; White et al., 2024). Luxton et al. (2024) outline a range of potential environmental, social, and design-based risks associated with the adoption of current nature positive aspirations. Renewable energy projects aiming to contribute to nature positive outcomes through biodiversity enhancement measures will need to consider many of these risks, including the ecological risks of restoration failure due to environmental drivers, limits to ecological and technical feasibility of enhancement measures, and the sufficiency of scientific knowledge needed to implement plans.

1.4 The business case for biodiversity enhancement

Biodiversity enhancement is of growing importance to project developers, for reasons in addition to biodiversity benefits. Biodiversity enhancement measures are one of the non-price criteria which are increasingly being used to distinguish between projects proposed as part of competitive renewable energy leasing rounds (WindEurope, 2020). For example, the tender criteria for the IJmuiden ver Alpha (Rijksdienst voor Ondernemend Nederland, 2023a) and IJmuiden ver Gamma (Rijksdienst voor Ondernemend Nederland, 2023b) offshore wind farms in the Netherlands included a requirement for measures to increase the habitat available for species native to the North Sea. Similarly, in Scotland, proposals for onshore wind farms will only be supported where it can be demonstrated that they will 'conserve, restore and enhance biodiversity, including nature networks, so they are in a demonstrably better state than without intervention' (Scotland's Nature Agency/Buidheann Nàdair na h-Alba, 2024). Beyond the requirements introduced by bidding criteria, some biodiversity enhancement measures may also offer the potential to reduce operational management costs and/or increase efficiency.

Businesses are increasingly being required to report on and disclose their interactions with nature and biodiversity, including risks, impacts, and opportunities for action – which encompasses biodiversity enhancement. For example:

- In Europe, there is a mandatory requirement for companies subject to the Corporate Sustainability Reporting Directive (CSRD) to report according to European Sustainability Reporting Standards (ESRS), including ESRS E4 on Biodiversity and Ecosystems. ESRS E4 includes a requirement to disclose policies adopted to "address production…. or consumption from ecosystems that are managed to maintain or enhance conditions for biodiversity, as demonstrated by regular monitoring and reporting of biodiversity status and gains or losses" (EFRAG, 2022, p. 9).

- There are also several voluntary frameworks and standards driving voluntary reporting and disclosure, for which there are increasing expectations for company alignment:

  - Companies aligning with the Taskforce on Nature-related Financial Disclosures (TNFD) are recommended to disclose nature-related opportunities, including enhancement actions beyond the management of impacts such as 'conservation, restoration and nature-based solutions' (TNFD, 2023, p. 27). TNFD sectoral guidance for 'Electric utilities and power generators' mentions examples of on-site habitat enhancement for pollinators at wind and solar farms (TNFD, 2024).

  - The Global Reporting Initiative (GRI) standard 101 on Biodiversity requires organisations to report on how they apply the mitigation hierarchy, which in addition to actions for avoidance, minimisation, restoration, rehabilitation and offsets also includes transformative actions and additional conservation actions. GRI 101 notes that 'additional conservation actions can be taken to create a positive impact on biodiversity beyond the management of the organisation's negative impacts'. (GRI, n.d., effective from January 2026).

Furthermore, for the increasing number of developers aiming to contribute to societal nature positive ambitions, biodiversity enhancement is a clear contribution beyond legislative or finance-linked requirements, or voluntary targets, for NNL or NPI of biodiversity. Biodiversity enhancement activities are a demonstrably proactive commitment to go beyond the minimum requirements and contribute to nature recovery, and they can provide ecosystem services benefits for project stakeholders (Section 1.3.2). Demonstrating that developments are bringing about positive changes for nature at the local level can bring significant benefits in terms of enhanced engagement and relationships with stakeholders. Consequently, such measures can be highly effective for increasing stakeholder buy-in and reducing opposition to renewable energy projects related to perceived impacts on biodiversity.

2.1 Solar

Currently, there is a growing evidence base on solar energy and the effectiveness of biodiversity enhancement, with most information coming from many countries, including Australia, Canada, Spain, UK, and USA (Boscarino-Gaetano et al., 2024). Solar projects located on transformed or degraded land offer opportunities for restoration, either of natural or semi-natural habitats (e.g. the restoration of pollinator habitats under and around solar panels, increasing native plant diversity (Evans et al,. 2023; Peschel, 2010). There are opportunities for the industry to contribute to nature recovery at scale, especially with the development of integrated policies focusing on the nexus between climate, nature, and land-use (Carvalho et al., 2024). Revegetation of areas beneath and around solar panels can increase biodiversity and create corridors for wildlife movement and dispersal, especially if fences are designed to allow movement of mammals and reptiles. Depending on vegetation management practices, solar developments can support higher levels of biodiversity than the surrounding arable landscape, when sited on agricultural land. This has been assessed at several sites across the UK for plants, birds, and invertebrates with higher diversity found at solar developments than the surrounding agricultural land (Carvalho et al., 2021; Montag et al., 2016). Thus, biodiversity enhancement at solar projects can directly improve ecosystem services and Nature-based Solutions that benefits the wider landscape (as outlined in Section 1.3.2).

The term 'ecovoltaics' is increasingly used to describe a dual land use approach of combining measures for biodiversity and solar power generation. In general, approaching solar array design and operation using an ecologically informed ecovoltaics approach (co-prioritising ecosystem services and energy generation) can bring multiple benefits for climate, biodiversity, and the restoration of degraded lands (Sturchio & Knapp, 2023). At the same, when considering the concept of ecovoltaics, it is helpful to differentiate between biodiversity enhancement actions and mitigation hierarchy actions, which are the actions most often implemented and described (Ljungström & Hörnelius, 2023). The concept of 'conservoltaics' – pairing solar projects with biodiversity conservation – has also been proposed to identify opportunities to directly incorporate both opportunities for solar energy generation and biodiversity conservation (Nordberg & Schwarzkopf, 2023). A third term is also in use – 'agrivoltaics' – pairing solar projects with agriculture.

Ecovoltaics, conservoltaics, and agrivoltaics can deliver various co-benefits for solar energy and biodiversity. These include land sparing, water use efficiency and water quality improvements, mass soil stabilisation and erosion control, and the maintenance of soil fertility, flood prevention, photovoltaic (PV) module efficiency in warm climates, as well as re-established wildflower meadows for grazing and increasing pollination services. Biodiversity enhancement measures offer an opportunity to bolster regenerative approaches that help ensure long-term sustainability of production systems, maintaining soil health and reducing the need for external inputs and the risk of environmental pollution.

Solar panels can also lead to the creation of a range of microhabitats that can provide optimal conditions for some species. For instance, for flora in a dryland ecosystem of the United States, the partial shading by solar panels delayed blooming and was shown to increase floral abundance during the late-season for pollinators (Graham et al., 2021). Overall, the presence of solar farms in agricultural landscapes may increase the structural diversity of habitats and increase avian diversity overall (Jarčuška et al., 2024).

In terms of bird nesting habitat, some incidental observations of generalist species of birds nesting under or on solar panels have been made. However, during a comparative study of 11 PV solar farms in the UK, ground-nesting skylarks tended to use undeveloped control plots more than the solar farms (Montag et al., 2016). This is presumably due to their requirements for open uninterrupted landscapes and the need to see predators approaching – which is likely to be similar for many grassland specialists. Case studies of solar PV over canals and hydroelectric reservoirs have demonstrated enhanced photovoltaic performance due to the cooler microclimate, as well as reduced evaporation and potentially the mitigation of excessive aquatic weed growth (Hernandez et al., 2019; McKuin et al., 2021).

There are many possible opportunities for biodiversity enhancement at solar farms (Table 2). Figure 2 summarises suitable ecological enhancements for a solar farm.[6] [7] In many cases, effective conservation actions from other non-renewable energy contexts will be appropriate biodiversity enhancement measures for solar developments. For example, the creation of ponds for amphibians (Smith et al, 2020) or the installation of nesting boxes and hibernacula that benefit a variety of bird, bat, amphibian, reptile, and insect species, as well as marsupials (Berthier et al., 2012; Boscarino-Gaetano et al., 2024; Lindenmayer et al., 2009; Pschonny et al., 2022; Sutherland et al., 2018). The effectiveness of bird boxes is well known, for example. They have been shown to increase the breeding success of the Eurasian oopoe (*Upupa epops*) in Central Europe (Berthier et al., 2012) and increase the number of breeding female soprano pipistrelle bats (*Pipistrellus pygmaeus*) in Spain (Flaquer et al., 2006). Specifically for solar energy, research is being conducted in the US to determine the suitability of releasing burrowing owls (*Athene cunicularia*) at solar farms (Ørsted, 2023), since this species is often rescued from development projects under US federal government permits and translocated to release sites with provision of artificial subterranean nest boxes. .

Benefits to pollinators are some of the most frequently implemented biodiversity enhancement actions at solar farms (Armstrong et al., 2021; Blaydes et al., 2021, 2022; Walston et al., 2023). Whilst more research is required to fully understand the potential for biodiversity enhancement at solar farms to benefit species and habitats beyond flora and pollinators, there is a range of opportunities and several examples are available, including EDF Renewables exploring positive impacts of solar energy in the UK (Scully, 2022), RWE piloting the creation of favourable conditions for biodiversity at solar farms in Poland (RWE, 2024), Regener8 Power's habitat creation in the UK (Regener8 Power, 2021-2023) and the ecovoltaics approach in Sardinia (Regener8 Power, 2021).

2.2 Onshore wind

Onshore wind farms present similar opportunities for habitat restoration to solar energy (Table 2), but often across larger areas and with fewer practical constraints. Individual wind turbines are widely spaced, leaving more opportunity for enhancement of the land in between. Some restoration measures may be implemented to compensate for loss of habitat due to roads and turbine pads, but additional areas for enhancement should be available, especially in projects sited on formerly degraded lands.

Most positive biodiversity actions for onshore wind tend to have been linked to impact mitigation, remediation, or offsetting actions; for example, contributions to breeding, and release of 35 California condors (*Gymnogyps californianus*) through the Wind Energy Condor Action Team (WECAT) programme.[8] However, some mitigation measures designed to minimise bird and bat collisions may also represent biodiversity enhancement to some extent. For example, increasing habitat attractiveness away from wind turbines to minimise potential black harrier collisions (Simmons et al., 2020); Excelsior Wind Farm[9] represents both a mitigation measure and an additional conservation outcome.

6 Please see Solar Energy UK (2022) for more information.
7 Tussocky field margins are areas where grass grows in clumps, bunches or tufts, or areas where thick masses of grass and other plants grow together. They provide essential habitat for invertebrates, and cover for and nesting sites for small mammals, as well as habitats for amphibians and reptiles.
8 For more information, please see: https://www.wecatllc.com
9 https://www.miga.org/sites/default/files/2019-09/Excelsior%20CHA%20Final%2029%20August%202019.pdf

Sustainable ecological enhancements for a solar farm

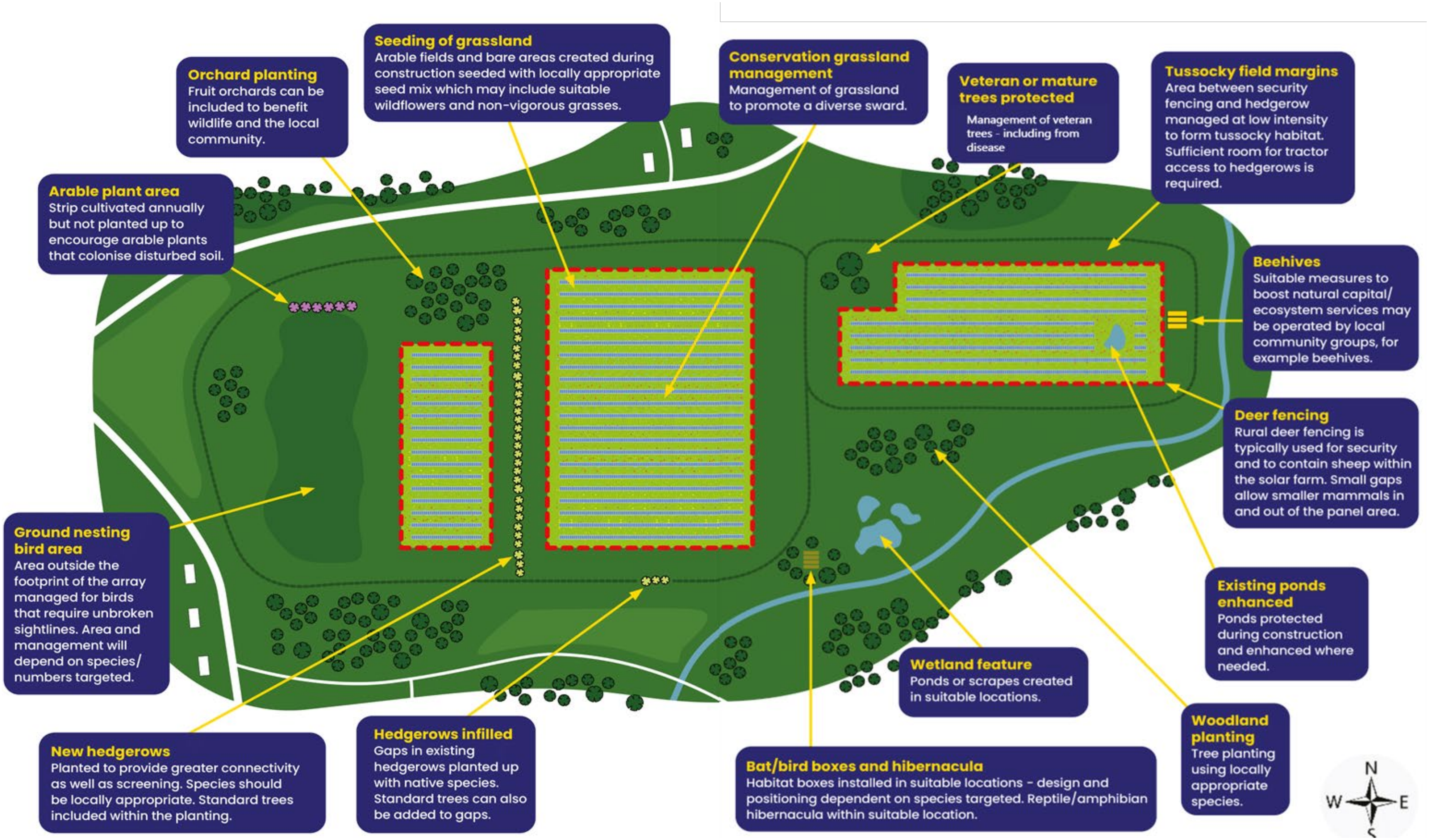

Figure 2 Examples of opportunities for biodiversity enhancement opportunities at PV solar developments *Source: Solar Energy UK (2022, pp. 24–25)*

In certain regions, it may be possible to demonstrate biodiversity enhancement through relatively passive means. For example, in the Gobi Desert, it has been demonstrated that wind dynamics downstream of turbines can alter local environmental conditions to such an extent that they improve habitat conditions and ecosystem functions without active management (Xu et al., 2019). These enhancements are relatively small scale (<40-90m downstream). However, over large numbers of turbines and on top of additional active restoration, they may lead to more significant ecosystem recovery. Importantly, these impacts are difficult to predict prior to construction and will vary from site to site with wake effects not only increasing but also potentially decreasing vegetation greenness (Diffendorfer et al., 2022). Figure 3 summarises potential generic biodiversity enhancement measures for an onshore wind farm. For more information on this figure, see Svegborn (2024). Many of these conservation measures are well tested actions that would also be effective at solar farms.

2.3 Offshore wind

The potential opportunities for offshore wind and biodiversity enhancement linked to the introduction of new structures below the sea surface in the marine environment have long been recognised (Inger et al., 2009). There is growing evidence of increases in fish abundance and epibenthic diversity within operational offshore wind farms (Methratta & Dardick, 2019; ter Hofstede et al., 2022). However,

Table 2 Documented examples of biodiversity enhancement opportunities in relation to onshore wind and solar energy

MEASURE*	TECHNOLOGY
Seeding with a diverse mix of native and locally appropriate flora species including wildflowers and non-vigorous grasses**	Onshore wind and solar
Seeding of crops to provide food for wild birds	Onshore wind and solar
Conservation management of grassland to produce a diverse sward (e.g. using periodic pulse grazing)	Onshore wind and solar
Avoiding vegetation cutting or grazing during spring to allow plants to flower and set seed, providing a longer foraging period for pollinators	Onshore wind and solar
Minimising chemical control of weeds and seed bare areas to prevent weed colonisation	Onshore wind and solar
Maintenance and creation of hedgerows increasing connectivity across the site. Avoid trimming hedgerows during the bird breeding season (often legally required)	Onshore wind and solar
Maintenance of open ground managed for ground-nesting birds or bare ground for invertebrates	Onshore wind and solar
Use of exclusion fencing where appropriate to prevent browsing and grazing of recovering woodland (e.g. deer fencing)	Onshore wind and solar
Creation of new habitats, such as ponds or wetland scrapes	Onshore wind and solar
Installation of bird and bat boxes or reptile and amphibian hibernacula	Onshore wind and solar
Restoring areas of dry and degraded peatlands (e.g. through peat hag reprofiling and damming gullies)	Onshore wind and solar
Enhancement of wildlife corridors and landscape connectivity focusing on riparian zones, project boundaries, access easements, steep slopes or rocky areas	Onshore wind (and solar where relevant)
Use of exclusion fencing where appropriate to prevent browsing and grazing of recovering woodland	Onshore wind and solar
Installation of reptile and amphibian hibernacula	Onshore wind and solar
Provision of refuges for wildlife using deadwood, rock	Onshore wind and solar
Removal of invasive or non-native species (if not already required by project)	Onshore wind and solar
Protecting wildlife from negative interactions with people	Onshore wind and solar

* Note the suitability of enhancement measures will vary considerably across geographies and local experts should always be consulted when selecting appropriate and effective measures at a site.
** For example, in the UK: https://www.suffolkbis.org.uk/sites/default/files/PDFs/2013%2003%20Notes%20RSPB%20solar%20enhancement%20talk%20notes.pdf; and in Australia: https://cpagency.org.au/wp-content/uploads/2024/05/Better_Biodiversity_on_Solar_Farm_Guide_May_2024.pdf

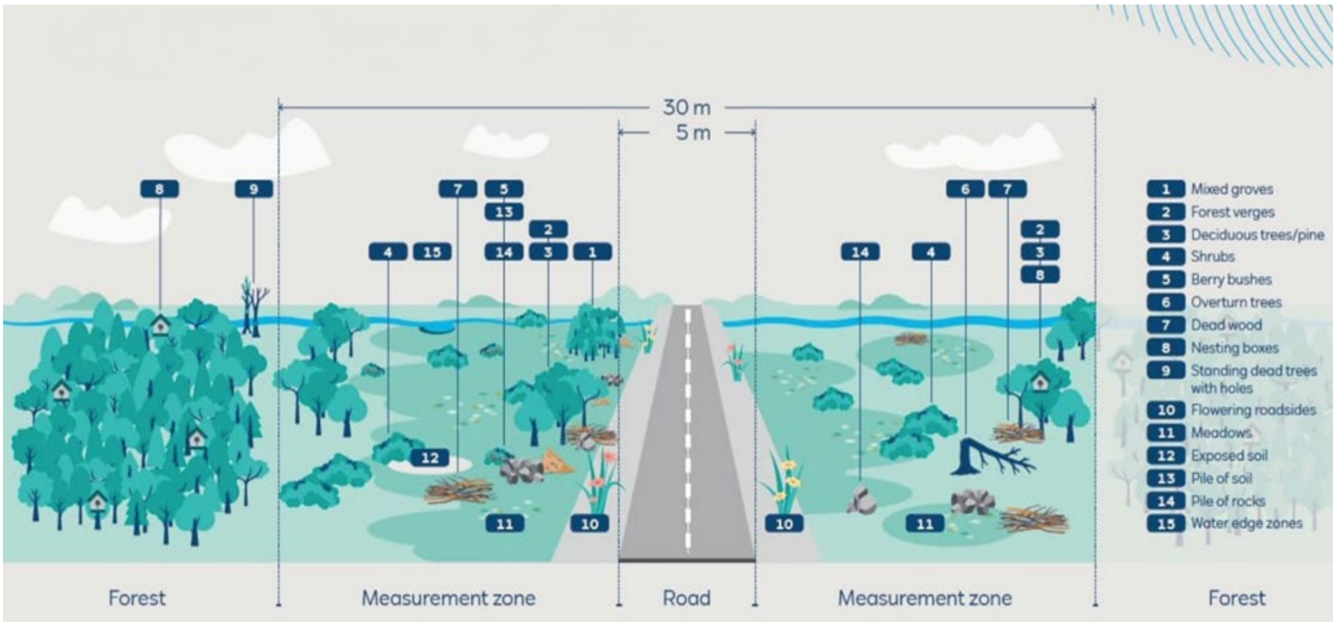

Figure 3 **Possible biodiversity enhancement measures for an onshore wind farm in a Nordic forest environment**
Source: Svegborn (2024, Figure 6.2, p. 52)

it is unclear whether this reflects the establishment of new populations, or a re-distribution of existing populations. For changes to reflect a net positive impact relative to the pre-project baseline, and therefore to represent biodiversity enhancement, any measures taken need to result in the establishment of new populations or measurable increase in existing populations.[10]

There has been substantial interest in understanding how new physical structures introduced into the marine environment could be adapted to offer opportunities for biodiversity enhancement (Figure 3), particularly in the North Sea (e.g. Inger et al., 2009). This interest has increased as regulators have introduced non-price criteria into offshore wind tenders and leasing rounds, often with a focus on biodiversity (see Section 1.3).

A recent review grouped measures for delivering nature-inclusive design for offshore wind farm into five broad groups: i) fish hotels/cage-type structures; ii) adapted rock protection measures; iii) reef-type structures and concrete blocks; iv) mattresses; and v) water replenishment holes (Crown Estate Scotland & Xodus, 2024).

A key area for biodiversity enhancement in relation to offshore wind farms relates to scour protection. Conventionally, scour protection has been formed from two layers – a lower layer with coarse gravel, topped with an armour layer made from larger rocks (Glarou et al., 2020). However, by incorporating rock with a greater range of sizes, it is possible to increase habitat heterogeneity, introducing crevices and other structures offering shelter to a range of species. While not explicitly identified as biodiversity enhancement, many early offshore wind developments applied similar measures. As monitoring data have been collected from operational wind farms, evidence has accumulated to support hypotheses surrounding the value of the heterogenous habitat introduced by carefully considered scour protection design, leading, for example, the Atlantic cod (*Gadus morhua*) to take advantage of new opportunities for shelter and foraging (Lindeboom et al., 2011). Developers have highlighted the potential for habitat creation around turbine foundations and scour protection as a positive impact associated with offshore wind farms (Vaissière et al., 2014).

As our understanding of the influence of scour and turbine structures on fish and benthic species has improved, developers and other companies are increasingly offering bespoke approaches to take advantage of this. Companies are trialling artificial structures made from a range of materials, including

10 Beyond the gains required to address any project-related adverse impacts.

concrete and steel, designed to mimic natural reefs with a variety of holes, crevices and hollows to attract marine life. These are being trialled and considered for use at several offshore wind farms.[11] As well as the size and shape of structures used for scour protection, careful thought is now also being given to the materials used. For example, marble has been shown to be associated with a higher prevalence of tube dwelling organisms, concrete is linked with free-living epi/endobiotic and crevice dwelling organisms, and granite has been found to be effective for establishing communities of shellfish, such as the flat oyster (*Ostrea edulis*) (Kingma et al., 2024; Tonk et al., 2020). Settlement of shellfish may be further enhanced through the incorporation of mussel shells, or other chalk-rich substrates, within the scour protection (Tonk et al., 2020).

Beyond designing underwater structures to encourage larval settlement and attract marine species, the potential to actively introduce target species is increasingly being considered (e.g. Kamermans et al., 2018). A key early focus for these efforts has been the establishment of flat oyster populations in operational offshore wind farms (Bos et al., 2023a), which has been piloted at locations including Gemini (Sas & Didderen, 2019) and Borssele III and IV of BlauWind[12] (Kamermans et al., 2018) wind farms in the North Sea.

In general, the importance of ecosystem restoration is increasingly recognised. For example, in the Humber Estuary, seagrass restoration is being undertaken in conjunction with the re-establishment of native oyster populations.[13] In addition to forming a biogenic reef that will support a range of marine wildlife, as filter feeders the oysters will help to achieve the improved water quality needed to maintain healthy seagrass. A similar approach is being trialled in Taiwan with attempts to encourage coral larvae to attach and grow on turbine foundation jackets.[14] The aim of measures such as these is not simply to establish new, self-sustaining populations of the species concerned, but to enhance the surrounding ecosystem, enabling it to support a broader range of marine species including fish, mammals and birds. Such effects may be further enhanced through the exclusion of fisheries from the footprint of the wind farm, creating a de facto marine protected area and providing spillover effects to improve neighbouring fisheries (Coates et al., 2016; Dunkley & Solandt, 2022).

Broadly, there are four design variables which could be used to optimise scour protection for better biodiversity outcomes (Lengkeek et al., 2017):

1) Adding larger structures to create holes (1–2 m) and crevices which will provide shelter for large mobile species such as the Atlantic cod (*Gadus morhua*).

2) Adding smaller structures than conventional scour protection to create small holes (a few centimetres) and crevices in which sediment can settle. This improves the habitat of egg, larvae or juvenile life stages of many species as well as improve the habitat quality of smaller species, such as rock gunnel (*Pholis gunnellus*) and the shore clingfish (*Lepadogaster lepadogaster*).

3) Providing or mimicking natural substrate chemical properties to improve habitat suitability for target species and facilitate settlement and growth. For example, chalk-rich substrate, such as concrete with added chalk or natural shells, improve settlement of European flat oyster (*Ostrea edulis L.*) larvae.

4) Active introduction of specimens of target species to enhance establishment of new populations.

Many biodiversity enhancement measures proposed, whether applied to scour protection, the turbine foundations, or other underwater infrastructure (such as protective enclosures to offer shelter and protection for young fish), fit within one or more of these categories (Figure 4).

11 For example, operated by RWE, Shell, and EDF.

12 Designing wind and solar projects to protect biodiversity: https://www.shell.com/news-and-insights/inside-energy-stories/designing-wind-and-solar-projects-that-help-protect-nature.html.

13 In the first phase of the project, 30 ha of seagrass meadow will be restored, aiming to provide habitat to support native oysters that will be released in the second half of the project: https://orsted.com/en/who-we-are/sustainability/nature/net-positive-biodiversity-impact/humber-biodiversity-restoration.

14 Growing corals on offshore wind turbines: https://orsted.com/en/who-we-are/sustainability/nature/net-positive-biodiversity-impact/recoral.

Figure 4 Examples of opportunities for biodiversity enhancement (or 'Nature Inclusive Design') at offshore wind develop *Source: OCEaN (2024)*

3 Considerations for effective enhancement

As well as a series of opportunities, there are challenges for delivering meaningful biodiversity enhancement at wind and solar farms and an appreciation of these can support better planning and more successful outcomes. In general, there is a lack of guidance specific to biodiversity enhancement practices and can be especially difficult in jurisdictions lacking clear biodiversity strategies and governance. Direction can be taken from countries with clearer expectations, including compensation or incentivisation for projects with biodiversity enhancement outcomes (CAN Europe, 2023).

Considerations for effective biodiversity enhancement should include:

- Understanding what constitutes biodiversity enhancement.
- Understanding the potential risks and/or unintended consequences of biodiversity enhancement.
- Managing spatial conflicts and other trade-offs.
- Competing priorities and cost effectiveness of biodiversity enhancement.

3.1 Understanding what constitutes biodiversity enhancement

This begins with being able to demonstrate the additionality of these actions above and beyond those mitigation requirements to compensate for the direct impacts of the project itself. Clarifying which actions are additional conservation actions above these mitigation measures will enable developers to consider actions more broadly in relation to their nature positive ambitions and without the constraint of being linked to a particular impact. This can enable more innovative approaches that can be designed in relation to broader priorities at the landscape or seascape scale. Challenges in maintaining both mitigation and enhancement-related gains exist, especially for offshore wind where regulations may require the removal of infrastructure (including that associated with an increase in biodiversity) during decommissioning.

3.2 Understanding the potential risks and unintended consequences

It is important to be aware of potential unintended consequences of enhancement measures, which may place barriers to future efforts. Whilst many measures may be tried and tested in other contexts, there is still a lack of information about implementation at wind and solar farms, and a need for knowledge sharing. Unintended consequences may undermine the efficacy of enhancement measures, such as the attraction of birds and bats vulnerable to collisions through the creation of feeding or breeding habitat, or via the potential for the establishment of non-native species (e.g. De Mesel et al., 2015). There is also the potential to create conflict with surrounding landowners by attracting, or providing a refuge for species of 'problem animals' (Rajvanshi et al., 2011). This may also pose an additional safety and practical management consideration for site workers, should shaded areas (for example, under solar panels in desertic areas) attract venomous snakes, spiders or scorpions to project sites.

3.3 Spatial conflicts and other trade-offs

Trade-offs between competing land and sea uses can present challenges for renewable energy and biodiversity enhancements (Battersby, 2023; Nordberg et al., 2021). Many of the areas suitable for renewable energy projects are suitable for multiple other uses that provide both environmental and social benefits, such as conservation grazing, fishing and aquaculture, and seaweed farming or bioenergy. Overlapping priorities to tackle climate change through the energy transition, ensure food security and mitigate biodiversity loss (OECD, 2020) leads to a risk that biodiversity enhancement

Power-generating windmills/Terrance Emerson

may displace these other activities. For example, artificial reef structures sited away from the turbine base may preclude bottom-towed fishing activity. Furthermore, there are risks activities elsewhere in the landscape potentially constraining or undermining site-level enhancement actions. For example, herbicide and pesticide drift or run-off can impact non-target species in adjacent landscapes. This means that there are often regulatory restrictions on what biodiversity enhancement measures can be applied and where these can be located, as well as specific criteria in renewable energy tenders specifying the type of enhancement that can be considered such as the IJmuiden ver Alpha and Gamma tenders (Section 1.3.3).

3.4 Competing priorities and cost effectiveness of actions

While biodiversity enhancement can improve stakeholder engagement, there are often conflicting interests among different stakeholders, and relatively low political priority may be given to biodiversity enhancement. Alongside insufficient funding, likely reflective of low political priority, these aspects are seen as the key socio-political barriers to ecological restoration in Europe and also likely to apply to biodiversity enhancement at wind and solar farms (Cortina-Segarra et al., 2021). Access to funding reflects a key challenge for biodiversity enhancements, given the relatively high costs associated with many active restoration measures (Brancalion et al., 2019; Díaz-García et al., 2020). At any rate, cost-effective biodiversity enhancement can be achieved through passive restoration or sharing costs with other developers in a region to promote biodiversity recovery at scale (e.g. European flat oyster reefs). Furthermore, implementing a combination of enhancement measures within the infrastructure of the project (e.g. scour protection and cable matrasses) can benefit both the project and local biodiversity.

As more projects start to integrate biodiversity enhancement measures and nature-inclusive design, costs will inevitably fall. In many offshore wind markets, however, one challenge is still the lack of suppliers to develop and supply commercial-scale enhancement technologies such as the structures that promote artificial reef development around scour protection for offshore wind farms.

4 Good practice principles for enhancement

Recommendations relating to biodiversity enhancement are increasingly being included in the guidance issued to developers by government regulators (e.g. NatureScot/Nàdar Alba, 2024; Ministry of Housing, Communities & Local Government, 2012), or provided by trade bodies (e.g. Solar Energy UK, 2022) and academic researchers such as the Nature+Energy project of MaREI of Ireland (SFI, n.d.). However, many of these documents merge recommendations on both mitigation hierarchy actions and biodiversity enhancement actions, leading to difficulties in differentiating between mandatory mitigation and remediation requirements and the voluntary additional actions developers could take to enhance biodiversity.

Based on the available literature and resources, a series of good practice principles for biodiversity enhancement are summarised in Table 3. Further information is provided in the following sections.

4.1 Target biodiversity enhancement actions on biodiversity directly linked to, associated with, or affected by the project

In contrast with avoidance, minimisation, restoration and offsets under the mitigation hierarchy, biodiversity enhancement can target any features connected to the project and the project ecological context. Ideally, selection of biodiversity enhancement measures will prioritise species of conservation concern or habitats with unfavourable status within the development footprint, but the scope can be broader and need not be limited to priorities identified through the project's environmental impact assessment, for example. Enhancement contributes to improving the resilience of the ecosystem impacted by a development (Rajvanshi et al., 2011). In doing so, it improves the capacity of that ecosystem to absorb pressures, including those associated with the development concerned. Thus, identifying what features to focus on could be informed by local biodiversity action plans and/or species-specific initiatives. This might include threatened species that utilise the broader project area but are not impacted by the project.

Biodiversity enhancement measures should initially be at the site level – within the footprint of the development itself or the area of influence. However, there may be circumstances where this is not appropriate (Section 1.3.1), and opportunities should be identified elsewhere within the landscape. For example, if a development is in an area of habitat which is already in good condition, opportunities for effective enhancement may be limited. Similarly, there is a need to ensure that enhancement measures are complementary to the project's other actions and do not undermine or conflict with existing mitigation actions. For example, if habitat improvement within the footprint of a wind farm risks attracting bird and bat species, and increasing their risk of collision with turbines, alternative options should be identified.

Consequently, the identification of suitable biodiversity enhancement measures should be made on a site-by-site basis, ensuring that they are appropriate for the landscape and seascape within which they are being implemented, and targeting naturally occurring and priority habitats and species.

4.2 Consider approaches for biodiversity enhancement early in the project cycle

It is important that biodiversity is considered at an early stage in the project cycle (Rajvanshi et al., 2011). Many measures to enhance biodiversity can take several years to become established, and for positive impacts to become apparent. This is particularly true in degraded habitat and less productive ecosystems (Bullock et al., 2011).

Table 3 Guiding principles for biodiversity enhancement in wind and solar projects

PRINCIPLE		RATIONALE
1	Target biodiversity enhancement actions on components of biodiversity directly linked to, associated with, or affected by the project	Biodiversity enhancement should target features present in the project area and surrounding landscape or seascape context, whether or not they are directly or indirectly impacted by a project. Enhancement can improve ecosystem resilience and the ability of that ecosystem to absorb pressures, including those associated with the project concerned. Targeted enhancement, after impact-related goals (NNL/NPI) are met, maximises the value to project-relevant ecosystems.
2	Consider approaches for biodiversity enhancement early in the project cycle	Many biodiversity enhancement measures will require careful planning to implement and are likely to require time to become established. Successful biodiversity enhancement measures are likely to be those with a good grounding in science and evidence. This provides confidence that biodiversity enhancement measures can deliver the expected positive outcomes for biodiversity within the lifetime of the project.
3	Ensure biodiversity enhancement measures are evidence-based	
4	Establish biodiversity baseline at an early stage in the project cycle	To measure progress and demonstrate efficacy and success of biodiversity enhancement measures it is necessary to compare post-implementation biodiversity conditions to pre-implementation, baseline conditions.
5	Ensure biodiversity enhancement measures are additional to any measures proposed in relation to mitigating impacts according to the mitigation hierarchy	Restoration and offsetting should be targeted at the residual impacts associated with a project. Biodiversity enhancement should deliver gains that are additional to those required under the mitigation hierarchy.
6	Ensure biodiversity enhancement actions are measurable with clearly defined goals and outcomes.	Quantifiable targets are required to demonstrate biodiversity gains associated with enhancement measures. Enhancement outcomes can include better ecosystem management, improved protection, enhanced areas for biodiversity conservation, and/or improved ecosystem services.
7	Identify and scope biodiversity enhancement measures through a collaborative and participatory process of stakeholder engagement.	A stakeholder-inclusive approach will help to ensure that biodiversity enhancement is targeted effectively, take local objectives and regulations into consideration, reduce conflicts, and improve confidence and buy-in. Stakeholder types include relevant government agencies, conservation NGOs, civil society organisations, scientific and academic institutions, individual experts and specialists, and local communities and indigenous peoples. Partnerships with local organisations can help with the delivery and monitoring of proposed enhancement measures.
8	Plan to implement biodiversity enhancement measures within a timeframe relevant to the project concerned	Biodiversity enhancement measures can take time to establish, and may be disrupted by, e.g. construction activities. Consequently, it is important that they take place at an appropriate time in the project life cycle and are given sufficient time to establish.
9	Ensure appropriate management, monitoring and reporting requirements are implemented for biodiversity enhancement measures	Effective management and monitoring is key to measuring the efficacy of any implemented biodiversity enhancement measures. The outputs from this monitoring should be disseminated widely so that lessons can be learned for future projects.
10	Plan for biodiversity enhancement outcomes to be sustained in the long-term, and ideally in perpetuity, to deliver a lasting legacy from a project	Plan for biodiversity enhancement outcomes to be sustained in the long-term, and ideally in perpetuity, to deliver a lasting legacy from a project

Accordingly, to maximise the gains from any biodiversity enhancement measures, it is important that these should be considered and implemented at the earliest stage possible in the project cycle. Ideally, measures should be deployed prior to the construction of any project. In many cases, however, this may not be practical, for example in situations where restored habitat may be damaged by construction activity and/or where enhancement measures are dependent on the availability of project infrastructure, such as scour protection.

4.3 Ensure biodiversity enhancement measures are evidence-based

The design of biodiversity enhancement measures should be evidence-based to ensure resources are deployed with higher likelihood of successful conservation outcomes. A number of resources are available which developers could consult in order to facilitate this. These include:

- **IUCN's Species Threat Abatement and Restoration (STAR) metric (IUCN, n.d.; Turner, 2024):** This can enable developers to quantify the potential contributions that species threat abatement and habitat restoration activities within and across their projects can offer towards reducing global species extinction risk.

- **The Conservation Evidence Initiative (Conservation Evidence, n.d.):** This initiative includes an assessment of the likely evidence for, and efficacy of, 3,690 actions proposed to conserve biodiversity, for example evidence on creating artificial reefs.[15]

- **The Restore Innovation (2024):**[16] This is a data driven platform currently compiling over 70 examples of nature-inclusive design solutions for offshore wind.

Resources such as these can support the identification of potential options for biodiversity enhancement and help to assess the potential efficacy of these options. However, the potential for innovation and improving the evidence base for enhancement measures that are based on sound ecological principles should be encouraged. For example, at present, the Conservation Evidence Initiative highlights that there is no evidence with which to assess the efficacy of maintaining or restoring strips of undisturbed habitat between solar arrays for reptile populations. In this light, biodiversity enhancement at renewable energy projects has the potential to improve the evidence base for measures such as these.

4.4 Establish biodiversity baseline at an early stage in the project cycle

Regardless of the approach(es) adopted to deliver biodiversity enhancement, it is essential to assess their efficacy. This requires comparing the condition of biodiversity values pre- and post-implementation of any enhancement. Having identified potential enhancement measures, the baseline condition of the biodiversity feature(s) that these measures target should be established in order to facilitate this comparison (Robert, 2024). The baseline should reflect conditions prior to the implementation of any enhancement measures and the construction of the project concerned.

4.5 Ensure biodiversity enhancement measures are in addition to any measures proposed in relation to mitigating impacts according to the mitigation hierarchy

As highlighted in Section 1.2.2, biodiversity enhancement should be additional to any measures proposed in relation to restoration and offsetting under the mitigation hierarchy. Restoration and offsetting are intended to address the residual impacts on biodiversity associated with a project. While there are some instances where there may be overlap between measures used for biodiversity enhancement and those used in relation to restoration and offsetting (Table 1), the central aim for biodiversity enhancement should be to deliver

15 For more information, please see: https://www.conservationevidence.com/actions/2259
16 For more information, please see: https://restoreinnovation.com/

an improvement on baseline, or pre-construction, conditions, and not to mitigate for residual impacts.

4.6 Ensure biodiversity enhancement actions are measurable with clearly defined goals and outcomes

Combined with a robust evidence based (Section 4.3), explicit, precise, and measurable targets are key to understanding the efficacy of biodiversity enhancement (Díaz et al., 2020). In the absence of a measurable target, it is not possible to say whether the goals of biodiversity enhancement associated with a project have been successfully delivered (e.g. Butchart et al., 2016). Some conservation actions can be more difficult to quantify. These difficulties can be overcome by setting a combination of precise, short-term goals (e.g. to attract an additional breeding pair to the site), and longer-term, less precise goals (e.g. to ensure that the species persists on the site over the lifetime of the project (Tear et al., 2005). These goals should be defined in relation to baseline biodiversity conditions (Section 4.4). For example, measures can be targeted to address one or more of the following (Rajvanshi et al., 2011):

- Better ecosystem management (e.g. better management of existing protected areas, restoration of degraded areas, eradication of invasive alien species);
- Improved protection (e.g. creation of new protected areas, upgraded legal protection of existing protected areas);
- Enhanced areas for biodiversity conservation (e.g. establishment of dispersal corridors, addition of new habitats);
- Improved ecosystem services (e.g. increased biological productivity through better management, reduction in pressure on provisioning services, increasing ecosystem resilience).

4.7 Identify and scope biodiversity enhancement measures through a collaborative and participatory process of stakeholder engagement

Biodiversity enhancement should be planned and implemented in consultation and engagement with biodiversity specialists, local communities, and affected people. Engaging with stakeholders and partnering with local experts will often be the best method of identifying targets for biodiversity enhancement and ensuring the success of proposed measures. This includes making use of traditional knowledge from local communities and Indigenous Peoples, where available. Key organisations for developers to engage are likely to include government agencies, environmental NGOs, native plant nurseries, local communities, Indigenous Peoples, academics, and other researchers. By developing a collaborative, stakeholder-inclusive approach through engagement with these organisations, developers will benefit by ensuring that proposed biodiversity enhancement measures are in line with local conservation objectives and comply with local and national regulations. This should include ensuring that the flow of ecosystem services from sources to beneficiaries is not disrupted and recognising the use of natural resources by local communities, Indigenous Peoples and other groups whose livelihoods depend on biodiversity.

Effective stakeholder engagement has led to the establishment of several successful partnerships for delivering biodiversity enhancement in relation to renewable energy projects, such as: Solarcentury and Bumblebee Conservation Trust partnering to promote the development of bee-friendly environments by creating biodiverse spaces at solar farms; Lightrock partnership with Royal Society for the Protection of Birds (RSPB) to seek their expert advice on going beyond biodiversity net gain requirements; VELUX Group and BayWa r.e. partnering with Universidad de Córdoba and Universidad Autónoma de Madrid to develop biodiversity enhancement measures; Ørsted partnerships with The Nature Conservancy (TNC) to donate Smiley-Woodfin Native Prairie for protection, with The Conservation Fund, and TNC to support voluntary land conservation and restoration activities on up to 3,000 acres of tallgrass prairie habitat within the Kansas Flint Hills; and Playa Lakes Joint Venture to restore and conserve 500 acres of playas wetland habitat for migratory birds in West Texas. Building on the success of these partnerships, programmes are being developed to provide direct support and advice to developers. For example, the Bee & Butterfly Habitat Fund 'Solar Synergy' programme, which provides tools and expertise to utility-scale solar developers seeking to cultivate high-quality pollinator habitats and understand carbon sequestration potential at their projects.

4.8 Plan to implement biodiversity enhancement measures within a timeframe relevant to the project concerned

In general, measures to offset, or compensate for, residual impacts under the mitigation hierarchy should be in place before the construction of a renewable energy project begins. This should also be the case for biodiversity enhancement measures that are deployed outside a renewable energy project footprint. For those measures which are applied within the footprint of a project, this may not always be practical. For example, deploying artificial structures in order to provide biodiversity enhancement of scour protection in offshore wind farms, is unlikely to be feasible before the turbines and cabling are in place. Similarly, attempts to restore native vegetation in a renewable energy project located within a degraded site may be negatively impacted by construction activity, and thus, best carried out once construction is complete. However, in order to increase the likelihood of enhancement delivering a lasting legacy for biodiversity measures should be put in place at as early a stage as possible.

4.9 Ensure appropriate management, monitoring, and reporting requirements are implemented for biodiversity enhancement measures

It is important to monitor and report progress towards the targets identified (Section 4.7) in relation to implemented biodiversity enhancement measures. As well as providing transparency, this will help to identify lessons learned for future projects, maximising their chances of success and minimising the risk of repeating unsuccessful, or inappropriate, biodiversity enhancement measures. Recognising that enhancement measures may take some time before becoming properly established (Section 4.2), this monitoring and reporting should take place at regular intervals, and not left until the end of a project lifecycle. Monitoring should aim to track progress towards the stated targets and identify where there is a risk that these targets may not be met. This will support the adaptive management of biodiversity enhancement measures, helping to maximise the chances of delivering the stated goals of a project.

4.10 Plan for biodiversity enhancement outcomes to be sustained in the long term, and ideally in perpetuity, to deliver a lasting legacy from a project

The world faces twin, inter-connected crises in relation to climate and biodiversity loss. Biodiversity enhancement of renewable energy projects offers the potential to deliver gains for biodiversity in conjunction with addressing the climate crisis. However, the lifetime of renewable energy project may be relatively short (e.g. typical operational lifespan of an offshore wind farm is 25 years). To deliver a lasting legacy for biodiversity, it is important that plans are put in place from the outset to ensure that gains are sustained in the long term, and ideally in perpetuity. This includes ensuring that sufficient funds and capacity are in place (Rajvanshi et al., 2011), and requires effective stakeholder engagement to agree how enhancements can be maintained beyond the operational lifespan of a project.

5 Integrating biodiversity enhancement into a project

Considering biodiversity enhancement approaches early in the project cycle (i.e. during the project design phase) will lead to better conservation outcomes and require less effort and funds than retrofitting onsite measures to existing projects. Projects incorporating nature-inclusive design will necessarily need to consider biodiversity from the outset and may find it easier to demonstrate biodiversity enhancement. As the renewable energy transition progresses in the context of global goals for biodiversity and the emerging nature positive agenda, there are valuable opportunities for the industry to meaningfully contribute to both climate and nature recovery. Figure 5 indicates how considerations for biodiversity enhancement might be integrated into a simplified project planning cycle. The ‘La Métairie’ 55 MW solar site is TotalEnergies’ largest photovoltaic site in France with 126,000 panels spanning over 75 hectares (TotalEnergies, 2022).

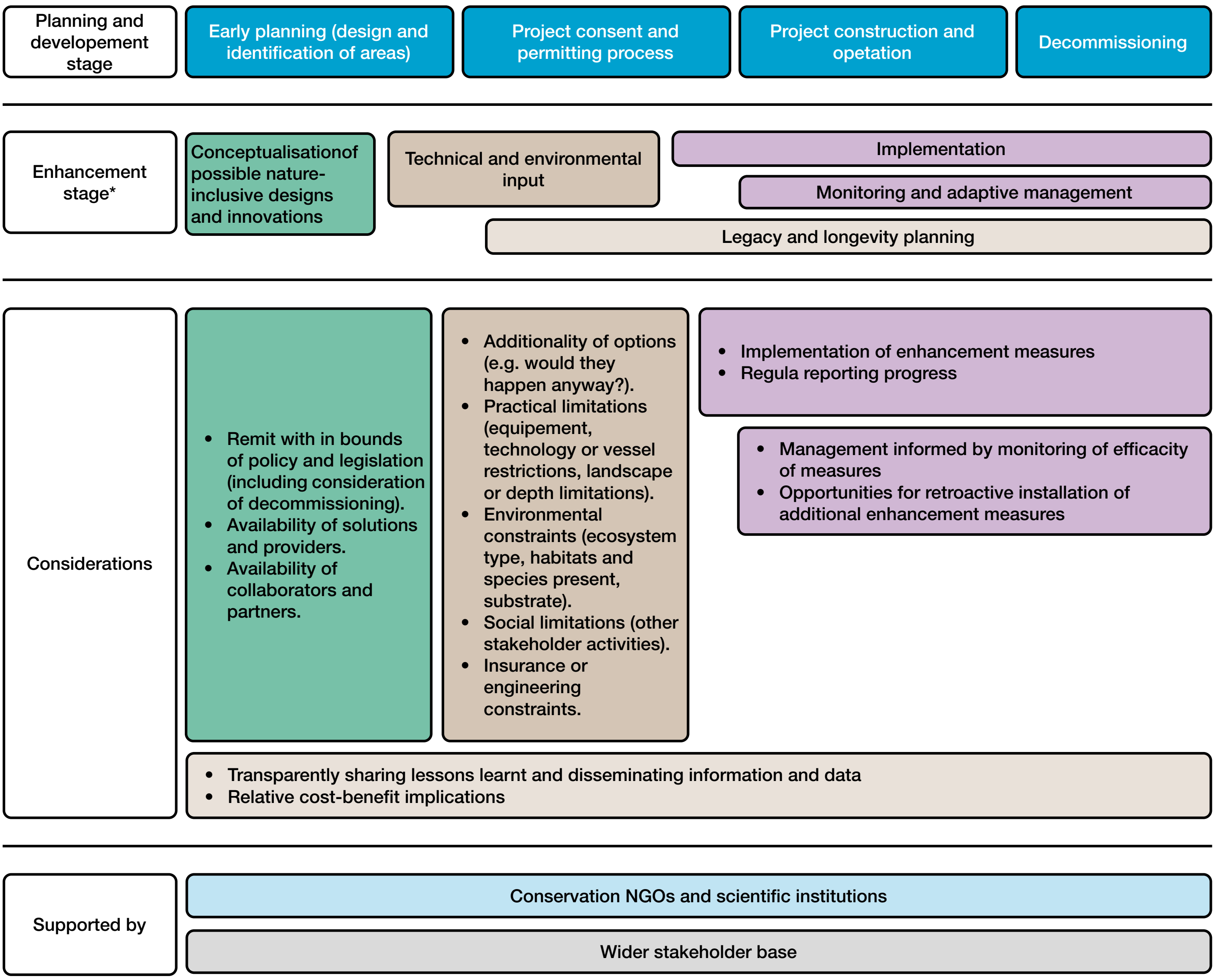

Figure 5 Integrating biodiversity enhancement into the project planning cycle*
Source: Authors

* Following, and not substituting, the implementation of the Mitigation Hierarchy.

6 Case studies

Case study 1 Biodiversity enhancement at La Métairie solar project (Gien, France)

The design and management plan of the site was developed in alignment with the mitigation hierarchy.

La Métairie began energy production in 2022 (Figure 6) and will provide for the requirements of 38,000 people while saving 19,000 tonnes of CO_2 per year.

Biodiversity enhancement measures were selected in addition to: (i) minimisation of forest clearance and mandatory financial contributions via a national forest compensation programme; (ii) compensation of impacts to bats through provision of additional roosting habitat; (iii) minimisation of barrier effects using wildlife permeable fencing for small species; and (iv) targeted offsite offsets.

Biodiversity enhancement measures created several additional wetland habitats for amphibians and invertebrates, and microhabitats to increase the numbers of reptiles and small mammals (Figure 7). Wildflower species were seeded using an appropriate mix of native species to increase habitats for pollinator species. Additionally, approximately 300 m of hedgerows were planted to increase connectivity and corridors for wildlife at the site.

Enhancement measures will remain in place for at least as long as the lifespan of the project (25–30 years). These measures were selected with the input of external experts during the design phase of the project and will be monitored by these experts to demonstrate biodiversity gains.

Lessons learned by TotalEnergies during this project include:

- Positive actions for biodiversity offer an opportunity to respond to the increasing concern of our stakeholders for nature conservation and improved local acceptability of operations.

Figure 6 *La Métairie* solar farm located in an area of natural ponds, forest, and agricultural land implementing mitigation hierarchy actions to their fullest extent to mitigate and remediate impacts
Photo: © TotalEnergies, 2022

Figure 7 Biodiversity enhancement measures created additional habitats in the form of wetlands, pollinator habitat, hedgerows to complement and enhance existing biodiversity features in the landscape
Photo: © TotalEnergies, 2022

- Positive actions for biodiversity should be medium / long term and be designed and implemented jointly with the local stakeholders and implementing partners to be meaningful.
- While the scrutiny of stakeholders tends to crystallise on a few large green field projects, there is actually a great opportunity for improving the biodiversity performance of the numerous existing production sites, and for implementing positive actions for biodiversity on a voluntary basis.

Such positive actions for conservation are easier to design than biodiversity offsets, as they do not claim to quantitively outweigh negative residual impacts and are not subject to the same scientific rigor.

Contributed by TotalEnergies SE

Case study 2 Biodiversity enhancement of peatland by onshore wind energy developers (Scotland)[17]

Peatland habitat covers more than a fifth of Scotland and, in addition to its significant carbon sequestration value, is home to a wide range of rare, threatened, or declining habitats, plants, and animals, including: sphagnum mosses, sundews, the large heath butterfly (Coenonympha tullia) and the bog sun jumper spider (Heliophanus dampfi). Four distinct types of peatlands exist in Scotland, including: blanket bogs, raised bogs, fens, and bog woodlands. The biodiversity and ecosystem service benefits of intact peatland and restoring degraded peatland at scale are well known (Benayas et al., 2009; Ramchunder et al., 2012). In Scotland, onshore wind projects are expected to submit a Habitat Management Plan setting out the scale of mitigation, compensation and enhancement of Peatland it will deliver (Scotland's Nature Agency/Buidheann Nàdair na h-Alba (2024).

ScottishPower Renewables currently manages approximately 8,500 hectares of peatland habitat with around half of the total area comprised of unplanted blanket bog, which has typically been historically damaged by a combination of drainage, overgrazing and burning. ScottishPower Renewables has spent £2.5 million on peatland restoration and research over the past 10 years and developed a new technique called 'wave damming' to increase the speed at which peat dams can be constructed and reduce peat disturbance. The new method also reduces the cost of building peat dams from around £2,600 per kilometre to around £350 per kilometre when dams are installed at five-metre intervals.

SSE Renewables actively manage 1,688 hectares of peatland habitat across 10 operational wind farms as part of a total of almost 20,000 hectares of land under Habitat Management Plans across Scotland. To enhance this habitat SSE Renewables have undertaken 253 hectares of targeted peatland restoration such as ditch blocking, 390 hectares of livestock reduction on sensitive peatland habitats and 355 hectares of forest removal to reduce the drying-out effect caused by trees. SSE Renewables has also implemented 'no muirburn' policies on 690 hectares of peatland habitat at its wind farm sites. As of 2020, SSE Renewables had committed to restore a further 330 hectares of peatland habitat across existing operational sites and sites which are currently under construction over the following five years.

Contributed by The Biodiversity Consultancy

17 This case study draws from the report, 'Wind power and peatland – enhancing unique habitats' (2020), produced by Scottish Renewables, Scotland's renewable energy industry association

Case study 3 Bonete solar plant (Albacete, Castilla La Mancha, Spain)

Bonete solar plant (Figure 8), Eni Plenitude Renewables Spain photovoltaic site, is comprised of two adjacent solar plants (Bonete II and Bonete III) located in Albacete, Castilla La Mancha (Spain), with a total surface area of 177 ha, that started operations in May 2020. The plant is part of a larger complex also currently including Bonete IV and Campanario & Campanario 1.

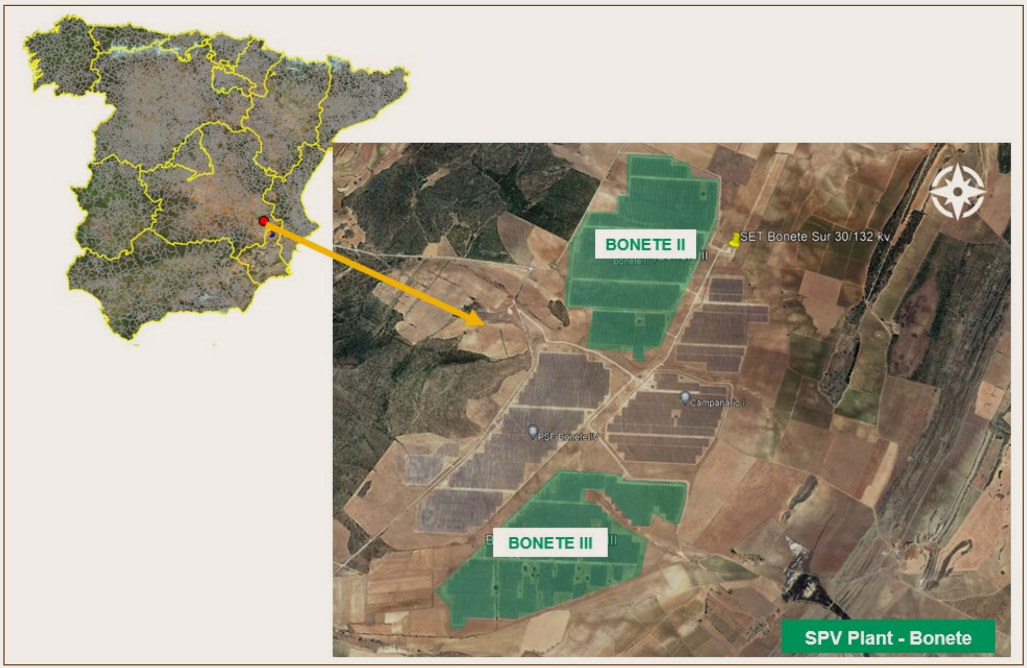

Figure 8 Bonete Solar Plant location

The plant is located within the Pétrola-Almansa-Yecla Key Biodiversity Area identified for great bustard (*Otis tarda)* and white-headed duck (*Oxyura leucocephala*), within 1 km of a Natura 2000 Special Protection Area (SPA) called 'Área Esteparia del Este de Albacete', which protects 10 priority steppe species and 10 habitats under the Nature Directives.

In compliance with environmental permits, a set of environmental measures following the mitigation hierarchy were implemented within the project; most of them continue to be managed during the operational phase, with special focus on biodiversity conservation.

Developing photovoltaic plants offers substantial benefits for biodiversity through various strategic practices. Within the Bonete solar plants, the vegetation is composed mainly of shrubs and annual herbs providing habitat for small birds and mammals. A key initiative in this regard is the vegetation management plan, which deliberately avoids the use of herbicides and agrochemicals. Initially, barley was planned for cultivation within the plant, a crop known for its heavy reliance on agrochemicals and intensive land management. However, this was replaced with meadows especially benefiting pollinators and also promoting a healthier and more diverse arthropod community.

By enhancing populations of arthropods, this boosts food availability for birds. For example, during recent years, a male little bustard (Tetrax tetrax) (Figure 9) selected a plot inside the Bonete plant as a lek area. Little bustards lek areas are related to high quality habitat that provides adequate resources for females and chicks.

In addition to the interior vegetation, extensive replanting with native species has been carried out in the surrounding area, along with a green screen that surrounds the entire plant; the survival of the replanting is regularly checked with monitoring of individuals during the Autumn.

Besides vegetation management, another measure has been the installation of nesting boxes for birds and bats. These nesting boxes provide essential nesting sites, which are often limited due to agricultural intensification and the subsequent loss of nesting sites. By increasing the availability of safe and suitable nesting places (Figure 10), this has encouraged the increase of bird and bat populations in the vicinity of the photovoltaic plants. This not only benefits these species directly but also contributes to maintaining a balanced ecological community. Birds and bats play significant roles in controlling insect populations, thus aiding in natural pest management for surrounding agriculture. Inside the plant, water feeders are placed to provide water for the wildlife. The plant is located in a very arid area, and these feeders are important to boost survival, especially for young individuals. Furthermore, to allow the passage of wildlife, the bottom part of the fence is raised above the ground (Figure 11). Additionally, the width of the fence openings is greater in the first 60 cm from the base. Terrestrial fauna, including the European wildcat (Felis silvestris), has been recorded passing through the plant (Figure 12). Furthermore, metal markers are installed on the fence to increase visibility and prevent birds from colliding with the wires.

In terms of partnerships, a collaborative agreement has been established with the owner of a nearby farm to implement agri-environmental measures. These measures are specifically designed to support the great bustard (Otis otis) and other steppe birds, which are threatened due to habitat loss from agricultural practices. The agri-environmental measures include habitat restoration actions such as creating suitable breeding and foraging grounds for these birds. By restoring and maintaining these habitats, we provide the necessary resources for these species to thrive, contributing to their conservation.

Contributed by Eni Plenitude S.p.A.

Figure 9 **Little bustard (*Tetrax tetrax*) within Bonete Solar Plant**
Photo: ©PlenitudeSpain, 2024

Figure 10 **Bird nest at Bonete Solar Plant**
Photo: ©PlenitudeSpain, 2024

Figure 11 **Wildflower habitat under panels**
Photo: ©PlenitudeSpain, 2024

Figure 12 **European wildcat (*Felis silvestris*)**
Photo: ©PlenitudeSpain, 2024

Case study 4 Oyster tables at Borssele III and IV Offshore Wind Farm

Blauwwind Wind Farm is a 77-turbine project in the Dutch North Sea with a capacity of 731.5 MW. Covering a total area of 146 km^2, it was fully commissioned in 2020.

The number of shellfish reefs in the North Sea has rapidly declined over the last century due to disease and overfishing. Windfarms are protected areas and trawler fishing is not permitted within a certain distance so the seabed is largely undisturbed and can provide shelter for marine life. To take advantage of these conditions and attempt to address the decline in North Sea shellfish reefs, the Blauwwind Consortium (which currently consists of Shell, INPEX, Eneco, Nuveen Infrastructure, Luxcara, and Swiss Life Asset Managers), in partnership with the Rich North Sea, developed a plan to kick-start a population of the native European flat oyster within the Blauwwind Wind Farm (Figure 13). To this end, in 2020, 2,400 flat oysters were placed on oyster tables around the base of wind turbines (Figure 14), it is hoped that eventually, the presence of oysters will attract other organisms to the area.

Figure 13 Oyster tables prior to deployment in Blauwwind Offshore Wind Farm
Photo: Shell International B.V.

Figure 14 Oyster table in situ within the Blawwind Offshore Wind Farm
Photo: Shell International B.V.

The pilot is monitored over a number of years but so far, the undisturbed waters below the wind turbines are having a positive impact on the oysters. After three years, survival rates of adult oysters were high, at around 70%, and 88% of these oysters were found to be ready for reproduction. In summer 2023, a monitoring campaign confirmed the presence of both young oysters that had established themselves amongst the original adults, and oyster larvae within the water column. In addition, the research used cameras on remotely operated vehicles (ROVs) and eDNA analysis to record marine life in the area. The research also looked at biodiversity within the wind farm using photo and video analyses, scrape samples and DNA analysis of water samples. They found no fewer than 128 species in total. Research is continuing on the site with a view to understanding how different materials influence larval settlement, and whether the population can avoid infection by the parasite *Bonamia ostrea*¸ which threatens existing populations.

Contributed by Shell International B.V.

References

Al-Dousari, A., Ramadan, A., Al-Qattan, A., Al-Ateeqi, S., Dashti, H., Ahmed, M., Al-Dousari, N., Al-Hashash, N., & Othman, A. (2020). Cost and effect of native vegetation change on aeolian sand, dust, microclimate and sustainable energy in Kuwait. *Journal of Taibah University for Science*, 14: 628–639. https://doi.org/10.1080/16583655.2020.1761662

Andersen, J. H., Al-Hamdani, Z., Harvey, E. T., Kallenbach, E., Murray, C., & Stock, A. (2020). Relative impacts of multiple human stressors in estuaries and coastal waters in the North Sea–Baltic Sea transition zone. *Science of The Total Environment*, 704(2020): 135316. https://doi.org/10.1016/j.scitotenv.2019.135316

Armstrong, A., Brown, L., Davies, G., Whyatt, J. D., & Potts, S. G. (2021). Honeybee pollination benefits could inform solar park business cases, planning decisions and environmental sustainability targets. *Biological Conservation*, 263: 109332. https://doi.org/10.1016/j.biocon.2021.109332

Battersby, S. (2023). How to expand solar power without using precious land. *Proceedings of the National Academy of Sciences*, 120(9): e2301355120. https://doi.org/10.1073/pnas.2301355120

Benayas, J. M. R., Newton, A. C., Diaz, A., & Bullock, J. M. (2009). Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis. *Science*, 325(5944):1121–1124. https://doi.org/10.1126/science.1172460

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

Berthier, K., Leippert, F., Fumagalli, L., & Arlettaz, R. (2012). Massive Nest-Box Supplementation Boosts Fecundity, Survival and Even Immigration without Altering Mating and Reproductive Behaviour in a Rapidly Recovered Bird Population. *PLoS ONE*, 7(4): e36028. https://doi.org/10.1371/journal.pone.0036028

Blaydes, H., Gardner, E., Whyatt, J. D., Potts, S. G., & Armstrong, A. (2022). Solar park management and design to boost bumble bee populations. *Environmental Research Letters*, 17(4): 044002. https://doi.org/10.1088/1748-9326/ac5840

Blaydes, H., Potts, S. G., Whyatt, J. D., & Armstrong, A. (2021). Opportunities to enhance pollinator biodiversity in solar parks. *Renewable and Sustainable Energy Reviews*, 145: 111065. https://doi.org/10.1016/j.rser.2021.111065

Blaydes, H., Potts, S. G., Whyatt, J. D., & Armstrong, A. (2024). *On-site floral resources and surrounding landscape characteristics impact pollinator biodiversity at solar parks*. EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-2180. https://doi.org/10.5194/egusphere-egu22-2180

Booth, H., Milner-Gulland, E. J., McCormick, N., & Starkey, M. (2024). Operationalizing transformative change for business in the context of Nature Positive. *One Earth*, 7(7): 1235–1249. https://doi.org/10.1016/j.oneear.2024.06.003

Bos, O. G., Duarte-Pedrosa, S., Didderen, K., Bergsma, J. H., Heye, S., & Kamermans, P. (2023a) Performance of European oysters (*Ostrea edulis L.*) in the Dutch North Sea, across five restoration pilots. *Frontiers in Marine Science*, 10: 1233744. https://doi.org/10.3389/fmars.2023.1233744

Bos, O. G., Kamermans, P., Tonk, L., Schutter, M., Maathuis, M., van Gool, A., van der Have, T., Bergsma, J., Raaijmakers, T., van Duren, L., Emmanouil, A., Gerritsma, I., Kleissen, F., & Sas, H. (2023b). *Eco-friendly reef restoration pilots in offshore wind farms. Report Project ECOFRIEND 2019-2023*. Den Helder, The Haque: Wageningen Marine Research. https://tethys.pnnl.gov/sites/default/files/publications/Bos-et-al-2023.pdf

Boscarino-Gaetano, R., Vernes, K., & Nordberg, E. J. (2024). Creating wildlife habitat using artificial structures: a review of their efficacy and potential use in solar farms. Biological Reviews, 99(5), 1848–1867. https://doi.org/10.1111/brv.13095

Brancalion, P. H. S., Meli, P., Tymus, J. R. C., Lenti, F. E. B., M. Benini, R., Silva, A. P. M., Isernhagen, I., & Holl, K. D. (2019). What makes ecosystem restoration expensive? A systematic cost assessment of projects in Brazil. Biological Conservation, 240, 108274. https://doi.org/10.1016/j.biocon.2019.108274

Bullock, J. M., Aronson, J., Newton, A. C., Pywell, R. F., & Rey-Benayas, J. M. (2011). Restoration of ecosystem services and biodiversity: conflicts and opportunities. *Trends in Ecology & Evolution*, 26: 541–549. https://doi.org/10.1016/j.tree.2011.06.011

Bureau Waardenburg (2020). Options for biodiversity enhancement in offshore wind farms. Knowledge base for the implementation of the Rich North Sea Programme. Culemborg, The Netherlands: Bureau Waardenburg. 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

Butchart, S. H. M., Di Marco, M., & Watson, J. E. M. (2016). Formulating Smart Commitments on Biodiversity: Lessons from the Aichi Targets. *Conservation Letters*, 9(6): 457–468. https://doi.org/10.1111/conl.12278

Carvalho, F., Armstrong, A., Ashby, M., Howell, B., Montag, H., Parker, G., Cruz, J., White, P., & Smart, S. (2021). *Assessing the impact of land-use change for solar park development in the UK: implications for biodiversity and ecosystem services*. EGU General Assembly 2021, 19–30 April 2021, EGU21-1271. Retrieved from https://doi.org/10.5194/egusphere-egu21-1271

Carvalho, F., Lee, H. K., Blaydes, H., Treasure, L., Harrison, L. J., Montag, H., Vucic, K., Scurlock, J., White, P. C. L., Sharp, S. P., Clarkson, T., & Armstrong, A. (2024). Integrated policymaking is needed to deliver climate and ecological benefits from solar farms. *Journal of Applied Ecology*, 00: 1–8. https://doi.org/10.1111/1365-2664.14745

Chemisana, D. & Lamnatou, Chr. (2014). Photovoltaic-green roofs: An experimental evaluation of system performance. *Applied Energy*, 119: 246–256. https://doi.org/10.1016/j.apenergy.2013.12.027

Choi, C. S., Macknick, J., Li, Y., Bloom, D., McCall, J., & Ravi, S. (2023). Environmental Co-Benefits of Maintaining Native Vegetation With Solar Photovoltaic Infrastructure. *Earth's Future*, 11(6): e2023EF003542. https://doi.org/10.1029/2023ef003542

Climate Action Network (CAN) Europe (2023). *Guidelines to Faster and Fairer Permitting for Europe's Renewable Energy Transition*. Brussels, Belgium: CAN Europe. https://caneurope.org/content/uploads/2023/10/Fairer-and-Faster-permitting_CAN-Europe-Briefing.pdf

Coates, D. A., Kapasakali, D.-A., Vincx, M., & Vanaverbeke, J. (2016). Short-term effects of fishery exclusion in offshore wind farms on macrofaunal communities in the Belgian part of the North Sea. *Fisheries Research*, 179: 131–138. https://doi.org/10.1016/j.fishres.2016.02.019

Community Power Agency (2024). *Building Better Biodiversity On Solar Farms: A regenerative guide to nature-positive solar farming*. Guidance document. New South Wales, Australia: Community Power Agency. https://cpagency.org.au/wp-content/uploads/2024/05/Better_Biodiversity_on_Solar_Farm_Guide_May_2024.pdf

Coolen, J. W. P., Lengkeek, W., van der Have, T., & Bittner, O. (2019). *Upscaling positive effects of scour protection in offshore wind farms. Quick scan of the potential to upscale positive effects of scour protection on benthic macrofauna and associated fish species*. Wageningen, The Netherlands: Bureau Waardenburg B.V. https://library.wur.nl/WebQuery/wurpubs/fulltext/475354

Cortina-Segarra, J., García-Sánchez, I., Grace, M., Andrés, P., Baker, S., Bullock, C., Decleer, K., Dicks, L. V., Fisher, J. L., Frouz, J., Klimkowska, A., Kyriazopoulos, A. P., Moreno-Mateos, D., Rodríguez-González, P. M., Sarkki, S., & Ventocilla, J. L. (2021). Barriers to ecological restoration in Europe: expert perspectives. *Restoration Ecology*, 29(4): e13346. https://doi.org/10.1111/rec.13346

Cross-Sector Biodiversity Initiative (CSBI) & The Biodiversity Consultancy (TBC) (2015). *A cross-sector guide to implementing the Mitigation Hierarchy*. Cambridge, UK: Cross-Sector Biodiversity Initiative. http://www.csbi.org.uk/our-work/mitigation-hierarchy-guide/

Crown Estate Scotland & Xodus (2024). *Collaboration for Environmental Mitigation & Nature Inclusive Design (CEMNID)*. Final Report. https://www.offshorewindscotland.org.uk/media/kcghvske/collaboration-for-environmental-mitigation-nature-inclusive-design-full-report.pdf

Dasgupta, P. (2021). *The economics of biodiversity: the Dasgupta review*. London, UK: HM Treasury. https://assets.publishing.service.gov.uk/media/602e92b2e90e07660f807b47/The_Economics_of_Biodiversity_The_Dasgupta_Review_Full_Report.pdf

De Mesel, I., Kerckhof, F., Norro, A., Rumes, B., & Degraer, S. (2015). Succession and seasonal dynamics of the epifauna community on offshore wind farm foundations and their role as stepping stones for non-indigenous species. *Hydrobiologia*, 756, 37–50. https://doi.org/10.1007/s10750-014-2157-1

Díaz, S., Zafra-Calvo, N., Purvis, A., Verburg, P. H., Obura, D., Leadley, P., Chaplin-Kramer, R., De Meester, L., Dulloo, E., Martín-López, B., Shaw, M. R., Visconti, P., Broadgate, W., Bruford, M. W., Burgess, N. D ., Cavender-Bares, J., DeClerck, F., Fernández-Palacios, J. M., Garibaldi, L.A., … & Zanne, A. E. (2020). Set ambitious goals for biodiversity and sustainability. *Science*, 370(6515): 411–413. https://doi.org/10.1126/science.abe1530

Díaz-García, J. M., López-Barrera, F., Pineda, E., Toledo-Aceves, T., & Andresen, E. (2020) Comparing the success of active and passive restoration in a tropical cloud forest landscape: A multi-taxa fauna approach. *PLoS ONE*, 15(11): e0242020. https://doi.org/10.1371/journal.pone.0242020

Diffendorfer, J. E., Vanderhoof, M. K., & Ancona, Z. H. (2022). Wind turbine wakes can impact down-wind vegetation greenness. *Environmental Research Letters*, 17(10), 104025. https://doi.org/10.1088/1748-9326/ac8da9

Dunkley, F., & Solandt, J.-L. (2022). Windfarms, fishing and benthic recovery: Overlaps, risks and opportunities. *Marine Policy*, 145, 105262. https://doi.org/10.1016/j.marpol.2022.105262

Dunne, D. (2022, June 16). *Explainer: Can climate change and biodiversity be tackled together?*. Carbon Brief. Retrieved from https://www.carbonbrief.org/explainer-can-climate-change-and-biodiversity-loss-be-tackled-together/

European Financial Reporting Advisory Group (EFRAG) (2022). *Draft European Sustainability Reporting Standards ESRS 4. Biodiversity and ecosystems*. Brussels, Belgium: EFRAG. https://www.efrag.org/sites/default/files/sites/webpublishing/SiteAssets/11%20Draft%20ESRS%20E4%20Biodiversity%20and%20ecosystems%20November%202022.pdf

Evans, M. J., Mainali, K., Soobitsky, R., Mills, E., & Minnemeyer, S. (2023). Predicting patterns of solar energy buildout to identify opportunities for biodiversity conservation. *Biological Conservation*, 283: 110074. https://doi.org/10.1016/j.biocon.2023.110074

Flaquer, C., Torre, I., & Ruiz-Jarillo, R. (2006). The value of bat-boxes in the conservation of Pipistrellus pygmaeus in wetland rice paddies. *Biological Conservation*, 128(2), 223–230. https://doi.org/10.1016/j.biocon.2005.09.030

Gasparatos, A., Doll, C. N. H., Esteban, M., Ahmed, A., & Olang, T. A. (2017). Renewable energy and biodiversity: Implications for transitioning to a Green Economy. *Renewable and Sustainable Energy Reviews*, 70: 161–184. https://doi.org/10.1016/j.rser.2016.08.030

Glarou, M., Zrust, M., & Svendsen, J. C . (2020). Using Artificial-reef Knowledge to Enhance the Ecological Function of Offshore Wind Turbine Foundations: Implications for Fish Abundance and Diversity. *Journal of Marine Science and Engineering*, 8: 332. https://doi.org/10.3390/jmse8050332

Global Report Initiative (GRI) (2024). *GRI 101: Biodiversity 2024*. Amsterdam, The Netherlands: GRI. https://www.globalreporting.org/pdf.ashx?id=24534

Graham, M., Ates, S., Melathopoulos, A. P., Moldenke, A. R., DeBano, S. J., Best, L. R., & Higgins, C. W. (2021). Partial shading by solar panels delays bloom, increases floral abundance during the late-season for pollinators in a dryland, agrivoltaic ecosystem. *Scientific Reports*, 11: 7452. https://doi.org/10.1038/s41598-021-86756-4

Hermans, A., Bos, O. G., & Prusina, I. (2020). *Nature-Inclusive Design: a catalogue for offshore wind infrastructure*. Technical report. Den Haag, The Netherlands: Witteveen+Bos. https://edepot.wur.nl/518699

Hernandez, R. R., Easter, S. B., Murphy-Mariscal, M. L., Maestre, F. T., Tavassoli, M., Allen, E. B., Barrows, C. W., Belnap, J., Ochoa-Hueso, R., Ravi, S., & Allen, M. F. (2014). Environmental impacts of utility-scale solar energy. *Renewable and Sustainable Energy Reviews*, 29: 766–779. https://doi.org/10.1016/j.rser.2013.08.041

Hernandez, R. R., Armstrong, A., Burney, J., Ryan, G., Moore-O'Leary, K., Diédhiou, I., Grodsky, S. M., Saul-Gershenz, L., Davis, R., Macknick, J., Mulvaney, D., Heath, G. A., Easter, S. B., Hoffacker, M. K., Allen, M. F., & Kammen, D. M. (2019). Techno–ecological synergies of solar energy for global sustainability. *Nature sustainability*, 2: 560–568. https://doi.org/10.1038/s41893-019-0309-z

Hoffacker, M. K., Allen, M. F., & Hernandez, R. R. (2017). Land-Sparing Opportunities for Solar Energy Development in Agricultural Landscapes: A Case Study of the Great Central Valley, CA, United States. *Environmental Science & Technology*, 51(24): 14472–14482. https://doi.org/10.1021/acs.est.7b05110

Inger, R., Attrill, M., Bearhop, S., Broderick, A. C., James Grecian, W., Hodgson, D. J., Mills, C., Sheehan, E., Votier, S. C., Witt, M. J., & Godley, B. J. (2009). Marine renewable energy: potential benefits to biodiversity? An urgent call for research. *Journal of Applied Ecology*, 46(6): 1145–1153. https://doi.org/10.1111/j.1365-2664.2009.01697.x

International Energy Agency (IEA) (2023). *World Energy Outlook 2023*. Paris, France: IEA. https://www.iea.org/reports/world-energy-outlook-2023. Licence: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A) (Available in Chinese, French, German, Italian, Polish, and Spanish.)

International Energy Agency (IEA), International Renewable Energy Agency (IRENA), United Nations Statistics Division (UNSD), World Bank, World Health Organization (WHO) (2023). *Tracking SDG 7: The Energy Progress Report*. Washington, DC, USA: World Bank. License: Creative Commons Attribution—NonCommercial 3.0 IGO (CC BY-NC 3.0 IGO). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2023/Jun/Tracking_SDG7_energy_progress_2023.pdf

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2022). *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. E. S. Brondízio, J. Settele, S. Díaz, H. T. Ngo (eds.). https://doi.org/10.5281/zenodo.3831673

International Union for Conservation of Nature (IUCN) (n.d.). *Species Threat Abatement and Restoration (STAR) metric*. IUCN. Retrieved from https://iucn.org/resources/conservation-tool/species-threat-abatement-and-restoration-star-metric

_____ (2020). *Ensuring effective Nature-based Solutions*. Issues Brief. Gland, Switzerland: IUCN. https://iucn.org/sites/default/files/2022-02/iucn_issues_brief_-_nbs_standard_eng.pdf

_____ (2022). *Towards an IUCN nature-positive approach: a working paper.* Summary highlights. Gland, Switzerland; IUCN. https://iucn.org/sites/default/files/2022-10/nature-positive-summary-highlihgts-oct-2022_0.pdf

Jarčuška, B., Gálffyová, M., Schnürmacher, R., Baláž, M., Mišík, M., Repel, M., Fulín, M., Kerestúr, D., Lackovičová, Z., Mojžiš, M., Zámečník, M., Kaňuch, P., & Krištín, A. (2024). Solar parks can enhance bird diversity in agricultural landscape. *Journal of Environmental Management*, 351: 119902. https://doi.org/10.1016/j.jenvman.2023.119902

Kamermans, P., Walles, B., Kraan, M., van Duren, L., Kleissen, F., van der Have, T., Smaal, A. C., & Poelman, M. (2018). Offshore Wind Farms as

Potential Locations for Flat Oyster (*Ostrea edulis*) Restoration in the Dutch North Sea. *Sustainability*, 10(11): 3942. https://doi.org/10.3390/su10113942

Kingma, E. M., ter Hofstede, R., Kardinaal, E., Bakker, R., Bittner, O., van der Weide, B., & Coolen, J. W. P. (2024). Guardians of the seabed: Nature-inclusive design of scour protection in offshore wind farms enhances benthic diversity. *Journal of Sea Research*, 199: 102502. https://doi.org/10.1016/j.seares.2024.102502

Knorrn, A. H., Teder, T., Kaasik, A., & Kreitsberg, R. (2024). Beneath the blades: marine wind farms support parts of local biodiversity - a systematic review. *Science of The Total Environment*, 935: 173241. https://doi.org/10.1016/j.scitotenv.2024.173241

Langhamer, O. (2012). Artificial Reef Effect in relation to Offshore Renewable Energy Conversion: State of the Art. *The Scientific World Journal*, 2012: 386713. https://doi.org/10.1100/2012/386713

Lengkeek, W., Didderen, K., Teunis, M., Driessen, F., Coolen, J. W .P., Bos, O. G., Vergouwen, S. A., Raaijmakers, T., de Vries, M. B., & van Koningsveld, M. (2017). *Eco-friendly design of scour protection: potential enhancement of ecological functioning in offshore wind farms. Towards an implementation guide and experimental set-up*. Culemborg, The Netherlands: Bureau Waardenburg. https://edepot.wur.nl/411374

Lima, J. S., Zalmon, I. R., & Love, M. (2019). Overview and trends of ecological and socioeconomic research on artificial reefs. *Marine Environmental Research*, 145: 81–96. https://doi.org/10.1016/j.marenvres.2019.01.010

Lindeboom, H. J., Kouwenhoven, H. J., Bergman, M. J. N., Bouma, S., Brasseur, S., Daan, R., Fijn, R. C., de Haan, D., Dirksen, S., van Hal, R., Hille Ris Lambers, R., ter Hofstede, Krijgsveld, K. L., Leopold, M., & Scheidat, M. (2011). Short-term ecological effects of an offshore wind farm in the Dutch coastal zone; a compilation. *Environmental Research Letters*, 6(3): 035101. http://dx.doi.org/10.1088/1748-9326/6/3/035101

Lindenmayer, D. B., Welsh, A., Donnelly, C., Crane, M., Michael, D., Macgregor, C., McBurney, L., Montague-Drake, R., & Gibbons, P. (2009). Are nest boxes a viable alternative source of cavities for hollow-dependent animals? Long-term monitoring of nest box occupancy, pest use and attrition. *Biological Conservation*, 142(1): 33–42. https://doi.org/10.1016/j.biocon.2008.09.026

Ljungström, M., & Hörnelius, J. (2023). *Ecovoltaics in Sweden. Views on integrating measures for biodiversity in solar parks*. Examensarbete för masterexamen (Master's Thesis), Industrial ecology. Department of Technology, Chalmers University of Technology, Gothenberg, Sweden. http://hdl.handle.net/20.500.12380/306209

Luxton, S. J., Smith, G. S., Williams, K J., Ferrier, S., Bond, A. J., & Prober, S. M. (2024). An introduction to key ecological concepts, financial opportunities, and risks underpinning aspirations for nature positive. *BioScience*, 74(7): 450–466. https://doi.org/10.1093/biosci/biae040

Macknick, J., Beatty, B., & Hill, G. (2013). *Overview of Opportunities for Co-Location of Solar Energy Technologies and Vegetation*. Golden, CO, USA: National Renewable Energy Laboratory (NREL). https://www.nrel.gov/docs/fy14osti/60240.pdf

Maron, M., Quétier, F., Sarmiento, M., Ten Kate, K., Evans, M. C., Bull, J.W., Jones, J. P. G., zu Ermgassen, S. O. S. E., Milner-Gulland, E. J., Brownlie, S., Treweek, J., & Von Hase, A. (2023). 'Nature positive' must incorporate, not undermine, the mitigation hierarchy. *Nature Ecology & Evolution*, 8: 14–17. https://doi.org/10.1038/s41559-023-02199-2

McKuin, B., Zumkehr, A., Ta, J., Bales, R., Viers, J. H., Pathak, T., & Campbell, J. E. (2021). Energy and water co-benefits from covering canals with solar panels. *Nature Sustainability*, 4: 609–617. https://doi.org/10.1038/s41893-021-00693-8

Methratta, E. T. & Dardick, W. R. (2019). Meta-Analysis of Finfish Abundance at Offshore Wind Farms. *Reviews in Fisheries Science & Aquaculture*, 27(2): 242–260. https://doi.org/10.1080/23308249.2019.1584601

Meyer, M. H., Dullau, S., Scholz, P., Meyer, M. A.,

& Tischew, S. (2023). Bee-Friendly Native Seed Mixtures for the Greening of Solar Parks. *Land*, 12(6): 1265. https://doi.org/10.3390/land12061265

Milner-Gulland, E. J. (2022). Don't dilute the term Nature Positive. *Nature Ecology & Evolution*, 6: 1243–1244. https://doi.org/10.1038/s41559-022-01845-5

Ministry of Housing, Communities & Local Government (2012, March 12). *National Planning Policy Framework*. GOV.UK. Retrieved from https://www.gov.uk/guidance/national-planning-policy-framework/15-conserving-and-enhancing-the-natural-environment

Montag, H., Parker, D. G., & Clarkson, T. (2016). *The Effects of Solar Farms on Local Biodiversity: A Comparative Study*. Somerset, UK: Clarkson & Woods and Wychwood Biodiversity. https://www.clarksonwoods.co.uk/download/Solar_Farms_Biodiversity_Study.pdf

Nature Positive Initiative (2023, November 27). *The Definition of Nature Positive*. Nature Positive Initiative. Retrieved from https://www.naturepositive.org/

Neugarten, R. A., Langhammer, P. F., Osipova, E., Bagstad, K. J., Bhagabati, N., Butchart, S.H.M., Dudley, N., Elliott, V., Gerber, L. R., Gutierrez Arrellano, C., Ivanić, K.-Z., Kettunen, M., Mandle, L., Merriman, J. C., Mulligan, M., Peh, K. S.-H., Raudsepp-Hearne, C., Semmens, D. J., Stolton, S., & Willcock, S. (2018). *Tools for measuring, modelling, and valuing ecosystem services: guidance for Key Biodiversity Areas, natural World Heritage Sites, and protected areas*. Gland, Switzerland: IUCN. https://doi.org/10.2305/IUCN.CH.2018.PAG.28.en

Nobre, R., Boulêtreau, S., Colas, F., Azemar, F., Tudesque, L., Parthuisot, N., Favriou, P., & Cucherousset, J. (2023). Potential ecological impacts of floating photovoltaics on lake biodiversity and ecosystem functioning. *Renewable and Sustainable Energy Reviews*, 188, 113852. https://doi.org/10.1016/j.rser.2023.113852

Nordberg, E. J., Julian Caley, M., & Schwarzkopf, L. (2021) Designing solar farms for synergistic commercial and conservation outcomes. *Solar Energy*, 228, 586–593. https://doi.org/10.1016/j.solener.2021.09.090

Nordberg, E. J., & Schwarzkopf, L. (2023). Developing conservoltaic systems to support biodiversity on solar farms. *Austral Ecology*, 48(3), 643-649. https://doi.org/10.1111/aec.13289

Offshore Coalition for Energy and Nature (OCEaN) (2024, June 1). *Nature Inclusive Design: Options for Offshore Wind Farms and Grid Infrastructure*. Offshore-coalition. Retrieved from https://offshore-coalition.eu/wp-content/uploads/2024/06/NID_Infographic_Ocean_2024.pdf

Organisation of Economic Co-operation and Development (OECD) (2020). *Towards Sustainable Land Use: Aligning Biodiversity, Climate and Food Policies*. Paris, France: OECD Publishing.

Ørsted A/S (2023, June 3). Ørsted Announces *Burrowing Owl Habitat Research Grant for Arizona State University*. Ørsted. Retrieved from https://us.orsted.com/news-archive/2023/03/orsted-announces-burrowing-owl-habitat-research-grant-for-arizona-state-university

_____ (2024a). *ReCoral. A new safe haven concept*. Ørsted. Retrieved from https://orsted.com/en/who-we-are/sustainability/nature/net-positive-biodiversity-impact/recoral

_____ (2024b). *Wilder Humber: Restoring Coastal Ecosystems. Restoring coastal ecosystems to mitigate climate change and support biodiversity*. Ørsted. Retrieved from https://orsted.com/en/who-we-are/sustainability/nature/net-positive-biodiversity-impact/humber-biodiversity-restoration

Parker, G. E. & Greene, L. (Eds.) (2014). *BRE National Solar Centre Biodiversity Guidance for Solar Developments*. Watford, Herts, UK: Building Research BRE. https://staploe-pc.gov.uk/wp-content/uploads/simple-file-list/Planning-Applications/Solar-Farm/BRE-guidance-for-biodiversity-and-solar.pdf

Peschel, T. (2010). *Solar parks - Opportunities for biodiversity. A report on biodiversity in and around* *ground-mounted photovoltaic plants.* Report No. 45. Berlin, Germany: German Renewable Energies Agency. http://irishsolarenergy.org/wp-content/uploads/2019/11/Solar-parks-Opportunities-for-Biodiversity.pdf

Pincebourde, S. & Woods, H. A. (2020). There is plenty of room at the bottom: microclimates drive insect vulnerability to climate change. *Current Opinion in Insect Science*, 41: 63–70. https://doi.org/10.1016/j.cois.2020.07.001

Pschonny, S., Leidinger, J., Leitl, R., & Weisser, W. W. (2022). What makes a good bat box? How box occupancy depends on box characteristics and landscape-level variables. *Ecological Solutions and Evidence*, 3(1): e12136. https://doi.org/10.1002/2688-8319.12136

Rajvanshi, A., Brownlie, S., Slootweg, R., & Arora, R. (2011.) Maximizing benefits for biodiversity: the potential of enhancement strategies in impact assessment. *Impact Assessment and Project Appraisal*, 29(3): 181–193. https://doi.org/10.3152/146155111x12959673796245

Ramchunder, S. J., Brown, L. E., & Holden, J. (2012). Catchment-scale peatland restoration benefits stream ecosystem biodiversity. *Journal of Applied Ecology*, 49(1): 182–191. https://doi.org/10.1111/j.1365-2664.2011.02075.x

Randle-Boggis, R., White, P. C. L., Cruz, J., Parker, G., Montag, H., Scurlock, J. M. O., & Armstrong, A. (2020). Realising co-benefits for natural capital and ecosystem services from solar parks: A co-developed, evidence-based approach. *Renewable and Sustainable Energy Reviews*, 125: 109775. https://doi.org/10.1016/j.rser.2020.109775

Regener8 Power (2021-2023). *UK Case Studies* [website]. Retrieved from https://regenera8.clientapps.sneekdigital.co.uk/portfolio/uk-case-studies/

_____ (2021). *150 MW in Sardinia, Italy* [website]. Retrieved from https://regener8power.com/portfolio/150-mw-in-sardinia-italy/

Rijksdienst voor Ondernemend Nederland (ROV) (National Office for Entrepreneurial Netherlands) (2023a). *IJmuiden Ver Wind Farm Zone Site Alpha*. ROV. Retrieved from https://english.rvo.nl/sites/default/files/2024-02/Wind-Farm-Site-Decision-IJmuiden-Ver-Alpha.pdf

Rijksdienst voor Ondernemend Nederland (ROV) (National Office for Entrepreneurial Netherlands) (2023b). *IJmuiden Ver Wind Farm Zone Site Beta*. ROV. Retrieved from https://english.rvo.nl/sites/default/files/2024-02/Wind-Farm-Site-Decision-IJmuiden-Ver-Beta.pdf

Robert, A. (2024). Building references for nature conservation. *Conservation Biology,* 38(2): e14202. https://doi.org/10.1111/cobi.14202

Roeleke, M., Blohm, T., Kramer-Schadt, S., Yovel, Y., & Voigt, C. C. (2016). Habitat use of bats in relation to wind turbines revealed by GPS tracking. *Scientific Reports*, 6: 28961. https://doi.org/10.1038/srep28961

Roser, M. (2020, December 10). *The world's energy problem*. Our World in Data. Retrieved from https://ourworldindata.org/worlds-energy-problem

RWE (2024, May 22). *International Day for Biological Diversity: RWE explores biodiversity enhancement at its photovoltaic farms in Poland*. Press release. RWE Poland. Retrieved from https://pl.rwe.com/-/media/RWE/RWE-Polen/press-and-news/2024/2024-05-22-rwe-explores-biodiversity-enhancement-at-its-photovoltaic-farms-in-poland.pdf

Sas, H., Didderen, K., van der Have, T., Kamermans, P., van den Wijngaard, K., & Reuchlin, E. (2019). *Recommendations for flat oyster restoration in the North Sea. Synthesis of lessons learned from the Dutch Voordelta experiments, with additional observations from flat oyster pilots in Borkum Reef and Gemini wind farm, modelling exercises and literature*. Nijmegen and Zeist, The Netherlands: ARK Rewilding Nederland and WWF Netherlands. https://arkrewilding.nl/sites/default/files/media/Schelpdierbanken/Recommendations_for_flat_oyster_restoration_in_the_North_Sea.pdf

Schneider, A.-K., Klabunde, F., Buck, L., Ohlhoff, M., Reis, L., Olvermann, M., Kauffeld, S., Engel, B., Glatzel, G., Schröder, B., & Frerichs, L.

(2023). Drawing transformation pathways for making use of joint effects of food and energy production with biodiversity agriphotovoltaics and electrified agricultural machinery. *Journal of Environmental Management*, 335: 117539. https://doi.org/10.1016/j.jenvman.2023.117539

Science Foundation Ireland (SFI) Research Centre for Energy, Climate and Marine (MaREI) (n.d.). *Nature+Energy*. MaREI, the SFI Research Centre for Energy, Climate and Marine. Retrieved from https://www.marei.ie/research/projects/natureenergy/

NatureScot/NàdarAlba (2024, November). *NatureScot pre-application guidance for onshore wind farms*. NatureScot/NàdarAlba. Retrieved from https://www.nature.scot/doc/naturescot-pre-application-guidance-onshore-wind-farms

Scully, J. (2022, June 8). *EDF to explore impact of utility-scale solar on biodiversity*. Solar Power Portal. Retrieved from https://www.solarpowerportal.co.uk/edf_to_explore_impact_of_utility_scale_solar_on_biodiversity/

Semeraro, T., Aretano, R., Barca, A., Pomes, A., Del Giudice, C., Gatto, E., Lenucci, M., Buccolieri, R., Emmanuel, R., Gao, Z., & Scognamiglio, A. (2020). A Conceptual Framework to Design Green Infrastructure: Ecosystem Services as an Opportunity for Creating Shared Value in Ground Photovoltaic Systems. *Land*, 9(8): 238. https://doi.org/10.3390/land9080238

Semeraro, T., Pomes, A., Del Giudice, C., Negro, D., & Aretano, R. (2018). Planning ground based utility scale solar energy as green infrastructure to enhance ecosystem services. *Energy Policy*, 117: 218–227. https://doi.org/10.1016/j.enpol.2018.01.050

Shi, H., Wen, Z., Paull, D., & Guo, M. (2016). A framework for quantifying the thermal buffering effect of microhabitats. *Biological Conservation*, 204(Part B): 175–180. https://doi.org/10.1016/j.biocon.2016.11.006

Simmons, R. E., Ralston-Paton, S., Colyn, R., & Garcia-Heras, M.-S. (2020). *Black Harriers and Wind Energy. Guidelines for impact assessment, monitoring and mitigation*. Johannesburg, South Africa: BirdLife South Africa. https://www.birdlife.org.za/wp-content/uploads/2020/09/Black-Harriers-Wind-Energy-Final-1.pdf

Sinha, P., Hoffman, B., Sakers, J., & 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

Smith, R. K., Meredith, H. & Sutherland, W. J. (2020) Amphibian Conservation. In: W. J. Sutherland, L.V. Dicks, S. O. Petrovan & R. K. Smith (eds.), *What Works in Conservation* (pp. 9–64). Open Book Publishers, Cambridge, UK. https://doi.org/10.11647/OBP.0191

Solar Energy UK (2022). *Natural Capital Best Practice Guidance. Increasing biodiversity at all stages of a solar farm's lifecycle*. London, UK: Solar Energy UK. https://solarenergyuk.org/wp-content/uploads/2022/05/Natural-Capital-Best-Practice-Guidance.pdf

Stenberg, C., Støttrup, J., van Deurs, M., Berg, C., Dinesen, G., Mosegaard, H., Grome, T., & Leonhard, S. (2015). Long-term effects of an offshore wind farm in the North Sea on fish communities. *Marine Ecology Progress Series*, 528: 257–265. https://doi.org/10.3354/meps11261

Sturchio, M. A. & Knapp, A. K. (2023). Ecovoltaic principles for a more sustainable, ecologically informed solar energy future. *Nature Ecology & Evolution*, 7: 1746–1749. https://doi.org/10.1038/s41559-023-02174-x

Sutherland, W. J., Dicks, L. V., Ockendon, N., Petrovan, S., & Smith, R. K. (2018). W*hat works in conservation*. Cambridge, UK: Open Book Publishers. https://doi.org/10.11647/OBP.0131

Svegborn, T. (2024). *Biodiversity Management in the Wind Power Industry - Examining Regulations, Incentives, and Corporate Practices Influencing Swedish Wind Power Companies*. Lund, Sweden: Lund University. https://lup.lub.lu.se/student-papers/search/publication/9149901

Swarnamaheswaran, K. (2023). Sustainable

Management of Green Corridors Below Overhead Lines in Europe. Master Thesis, Technische Universität Wien; Diplomatische Akademie Wien, ETIA 15. https://doi.org/10.34726/hss.2023.113075

Tansley, A. G. (1935). The Use and Abuse of Vegetational Concepts and Terms. Ecology, 16(3): 284–307. https://doi.org/10.2307/1930070

Taskforce on Nature-related Financial Disclosures (TNFD) (2023). Guidance on the identification and assessment of nature related issues: The LEAP approach. Version 1.1. London, UK: TNFD. https://tnfd.global/wp-content/uploads/2023/08/Guidance_on_the_identification_and_assessment_of_nature-related_Issues_The_TNFD_LEAP_approach_V1.1_October2023.pdf?v=1698403116

TNFD (2024). Additional sector guidance – Electric utilities and power generators. London, UK: TNFD. https://tnfd.global/wp-content/uploads/2024/06/Additional-Sector-Guidance-Electric-Utilities-and-Power.pdf?v=1719525999

Tear, T. H., Kareiva, P., Angermeier, P. L., Comer, P., Czech, B., Kautz, R., Landon, L., Mehlman, D., Murphy, K., Ruckelshaus, M., Scott, J. M., & Wilhere, G. (2005). How Much Is Enough? The Recurrent Problem of Setting Measurable Objectives in Conservation. BioScience, 55(10): 835–849. https://doi.org/10.1641/0006-3568(2005)055[0835:hmietr]2.0.co;2

ter Hofstede, R., Driessen, F. M. F., Elzinga, P. J., Van Koningsveld, M., & Schutter, M. (2022). Offshore wind farms contribute to epibenthic biodiversity in the North Sea. Journal of Sea Research, 185: 102229. https://doi.org/10.1016/j.seares.2022.102229

The Biodiversity Consultancy (TBC) (2022). Charting a course to nature positive. London, UK: TBC. https://www.thebiodiversityconsultancy.com/fileadmin/uploads/tbc/Documents/Resources/Charting_a_course_to_nature_positive_-_TBC_Insight.pdf

The Nature Conservancy (TNC) (2021, April 9). Perspectives: Smarter Energy Siting Helps Achieve Climate & Biodiversity Goals. TNC. Retrieved from https://www.nature.org/en-us/what-we-do/our-insights/perspectives/smarter-energy-siting-helps-climate-biodiversity/

Tonk, L., Witte, S., & Kamermans, P. (2020). Flat oyster (*Ostrea edulis*) settlement on scour protection material. Innovation Eco Scour Protection in offshore windfarm Borssele V. Wageningen Marine % Research report C063/20. Wageningen, Netherlands: Wageningen Marine Research. https://library.wur.nl/WebQuery/wurpubs/616188

TotalEnergies (2022, June 10). Centrale solaire de la Métairie : la biodiversité à l'honneur (La Métairie solar central: biodiversity in the spotlight). TotalEnergies. Retrieved from https://totalenergies.com/fr/news/centrale-solaire-de-la-metairie-la-biodiversite-lhonneur

Turner, J. A., Starkey, M., Dulvy, N. K., Hawkins, F., Mair, L., Serckx, A., Brooks, T., Polidoro, B., Butchart, S. H. M., Carpenter, K., Epps, M., Jabado, R. W., Macfarlane, N. B. W., & Bennun, L. (2024) Targeting ocean conservation outcomes through threat reduction. npj Ocean Sustainability, 3: 4. https://doi.org/10.1038/s44183-023-00040-8

Vaissière, A.-C., Levrel, H., Pioch, S., & Carlier, A. (2014). Biodiversity offsets for offshore wind farm projects: The current situation in Europe. Marine Policy, 48: 172–183. https://doi.org/10.1016/j.marpol.2014.03.023

Walston, L. J., Mishra, S. K., Hartmann, H. M., Hlohowskyj, I., McCall, J., & Macknick, J. (2018). Examining the Potential for Agricultural Benefits from Pollinator Habitat at Solar Facilities in the United States. *Environmental Science & Technology*, 52: 7566–7576. https://doi.org/10.1021/acs.est.8b00020.s001

Walston, L. J., Li, Y., Hartmann, H. M., Macknick, J., Hanson, A., Nootenboom, C., Lonsdorf, E., & Hellmann, J. (2021). Modeling the ecosystem services of native vegetation management practices at solar energy facilities in the Midwestern United States. *Ecosystem Services*, 47: 101227. https://doi.org/10.1016/j.ecoser.2020.101227

Walston, L. J., Barley, T., Bhandari, I., Campbell, B., McCall, J., Hartmann, H. M., & Dolezal, A. G. (2022). Opportunities for agrivoltaic systems to achieve synergistic food-energy-environmental needs and address sustainability goals. Frontiers in

Sustainable Food Systems, 6: 932018. https://doi.org/10.3389/fsufs.2022.932018

Walston, L. J., Hartmann, H. M., Fox, L., Macknick, J., McCall, J., Janski, J., & Jenkins, L. (2023). If you build it, will they come? Insect community responses to habitat establishment at solar energy facilities in Minnesota, USA. Environmental Research Letters, 19: 014053. https://doi.org/10.1088/1748-9326/ad0f72

Werner, K. M., Haslob, H., Reichel, A. F., Gimpel, A., & Stelzenmüller, V. (2024). Offshore wind farm foundations as artificial reefs: The devil is in the detail. *Fisheries Research*, 272: 106937. https://doi.org/10.1016/j.fishres.2024.106937

White, T. B., Bromwich, T., Bang, A., Bennun, L., Bull, J., Clark, M., Milner-Gulland, E. J., Prescott, G. W., Starkey, M., zu Ermgassen, S. O. S. E., & Booth, H. (2024). The "nature-positive" journey for business: A conceptual research agenda to guide contributions to societal biodiversity goals. *One Earth*, 7: 1373–1386. https://doi.org/10.1016/j.oneear.2024.07.003

Williams, H. J., Hashad, K., Wang, H., & Max Zhang, K. (2023) The potential for agrivoltaics to enhance solar farm cooling. *Applied Energy*, 332: 120478. https://doi.org/10.1016/j.apenergy.2022.120478

Wilson, J. C., & Elliott, M. (2009). The habitat-creation potential of offshore wind farms. *Wind Energy*, 12, 203–212. https://doi.org/10.1016/j.apenergy.2022.120478

WindEurope (2020). *WindEurope position on non price criteria in auctions*. Brussels, Belgium: WindEurope. https://windeurope.org/wp-content/uploads/files/policy/position-papers/20220413-WindEurope-Position-paper-non-price-criteria-in-auctions.pdf?20220520b

Wit, F., & Biesmeijer, K. (2020). *The effects of solar parks on plants and pollinators: the case of Shell Moerdijk*. Leiden, The Netherlands: Naturalis Biodiversity Center. https://www.naturalis.nl/system/files/inline/Report%20The%20effects%20of%20solar%20parks%20on%20plants%20and%20pollinators%20-%20the%20case%20of%20Shell%20Moerdijk%20_0.pdf

World Wide Fund for Nature (WWF) (2022). *Living Planet Report 2022 – Building a nature positive society.* Almond, R. E. A., Grooten, M., Juffe Bignoli, D., & Petersen, T. (Eds.). Gland, Switzerland: WWF. https://wwfint.awsassets.panda.org/downloads/embargo_13_10_2022_lpr_2022_full_report_single_page_1.pdf

World Wildlife Fund (WWF) & Boston Consulting Group (BCG) (2023). Building a Nature-Positive Energy Transformation: Why a low-carbon economy is better for people and nature. Washington, DC, USA: WWF. https://www.worldwildlife.org/publications/building-a-nature-positive-energy-transformation--2

WWF & The Biodiversity Consultancy (TBC) (2023). *Nature-safe energy: linking energy and nature to tackle the climate and biodiversity crises*. World Wildlife Fund and The Biodiversity Consultancy, Gland, Switzerland, and Cambridge, UK. https://wwfint.awsassets.panda.org/downloads/cleanaction_nature_safe_energy_report.pdf

Xu, K., He, L., Hu, H., Liu, S., Du, Y., Wang, Z., Li, Y., Li, L., Khan, A., & Wang, G. (2019). Positive ecological effects of wind farms on vegetation in China's Gobi desert. *Scientific Reports*, 9: 6341. https://doi.org/10.1038/s41598-019-42569-0

Zhang, B., Zhang, R., Li, Y., Wang, S., Zhang, M., & Xing, F. (2024). Deploying photovoltaic arrays in degraded grasslands is a promising win-win strategy for promoting grassland restoration and resolving land use conflicts. *Journal of Environmental Management*, 349: 119495. https://doi.org/10.1016/j.jenvman.2023.119495

zu Ermgassen, S. O. S. E., Howard, M., Bennun, L., Addison, P. F. E., Bull, J. W., Loveridge, R., Pollard, E., & Starkey, M. (2022). Are corporate biodiversity commitments consistent with delivering 'nature-positive' outcomes? A review of 'nature-positive' definitions, company progress and challenges. *Journal of Cleaner Production*, 379 (Part 2), 134798. https://doi.org/10.1016/j.jclepro.2022.134798

Annex Tabulated summary of existing approaches to biodiversity enhancement

Table of references to further examples and guidance on implementing biodiversity enhancement at wind and solar sites:

Table 5 Summary of existing definitions from literature, standards, regulations, and policies

ENHANCEMENT OPTIONS	KEY MESSAGES	PUBLICATION TYPE	REFERENCE
	SOLAR		
Use of degraded land	Assessing the impact of land-use change for solar park development in the UK. Concluded that, overall, the diversity of habitat indicator species seemed highly dependent on former land-use, showing that solar parks have the potential to enhance ecosystem services provision if built on degraded agricultural land.	Research paper	Carvalho et al., 2021
	Proposes techno-ecological synergy (TES) as an approach to improve sustainability of solar energy. Highlights the ecological and efficiency benefits of utilising degraded and contaminated land for solar farms, especially when this is coupled with restoration activities.	Research paper	Hernandez et al., 2014; 2019
	Evaluates the land sparing potential of solar farms sited in: the built environment, salt-affected agricultural land, contaminated land, and water reservoirs (as floatovoltaics) in California, USA. Identifies the potential techno-ecological synergistic outcomes of development in these landscapes.	Research paper	Hoffacker et al., 2017
	Case study of the 550 MW Topaz Solar Farms project, CA, USA, to show best practices in responsible land use. The habitat replaced by the Topaz project was actively farmed and treated annually with fertilisers, herbicides, and rodenticides. The Topaz project eliminated the annual disturbance regime, fertilisers, and use of rodenticides, allowing biodiversity to recover.	Case study and guidance	Sinha et al., 2018
	Study investigated soil and vegetation characteristics to assess the impacts of PV arrays on restoration in degraded grasslands in northeast China. Results showed that the PV arrays and fencing significantly improved soil and vegetation parameters, with increased carbon and nitrogen storage in plants and soil.	Research paper	Zhang et al., 2024
Colocation with other uses – e.g. agrivoltaics	Highlights the benefits of agrivoltaic systems (PV co-located with crop production), identifying 10 potential techno-ecological outcomes of agrivoltaics, including land sparing, as well as PV module efficiency, water use efficiency / water quality, erosion prevention and soil fertility maintenance. Additionally, the co-existence of grazing livestock, may reduce the need for vegetation removal and maintenance.	Research paper	Hernandez et al., 2014; 2019

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ENHANCEMENT OPTIONS	KEY MESSAGES	PUBLICATION TYPE	REFERENCE
SOLAR			
(continued) **Colocation with other uses – e.g. agrivoltaics**	Compared 11 solar farms and found that conservation grazing within the solar farm (winter and spring sheep grazing at lower stocking densities) was associated with increased botanical diversity over time. Higher botanical diversity was associated with higher insect and bird diversity.	Research paper	Montag et al., 2016
	Paper analysing opportunities of agrivoltaics systems, including benefits for biodiversity. Emphasises that agrivoltaics reduces the space required for both uses (solar and agriculture). The biodiversity benefits identified include provision of shelter, microhabitats, nesting and perching sites for birds (including ground-nesting birds), and protection for prey species. It also assesses benefits for agriculture, e.g. increased productivity.	Research paper	Nordberg et al., 2021
	Shows how 'biodiversity agriphotovoltaics', i.e. agriphotovoltaics in combination with biodiversity protection measures, such as flower strips, can contribute to promoting biotope connectivity in addition to significant energy production.	Research paper	Schneider et al., 2023
	A synthesis of potential ecosystem services of agrivoltaics. The article highlights how the establishment of solar-pollinator habitat at agrivoltaic systems could benefit biodiversity and aid conservation of some threatened species, as well as restoring ecosystem services such as crop pollination and pest control.	Literature review	Walston et al., 2022
	A numerical model was developed to investigate the microclimate of a solar farm, which was used to compare an agrivoltaic system to traditional PV. Results indicate up to 10 °C cooling benefit of solar panels in agrivoltaic systems, which can increase efficiency and solar module lifespan.	Research paper	Williams et al., 2023
Establishing pollinator-friendly habitats and management practices	A literature review of available evidence on how solar park land management practices can enhance pollinator biodiversity. This literature review was used to synthesise 10 evidence-based recommendations on how to improve solar park management for pollinators.	Literature review and guidance	Blaydes et al., 2021
	Research paper quantifying the impact of on-site floral resources and surrounding landscape characteristics on solar park pollinator biodiversity. Found that on-site floral species richness had the greatest influence on pollinator biodiversity at solar parks.	Research paper	Blaydes et al., 2024
	Guidance to planners and the solar industry on how they can support biodiversity on solar farms including suggestions of biodiversity enhancement measures.	Guidance	Parker & Greene, 2014
	Used a modelling framework to investigate potential responses of pollinator supply to native grassland habitat restoration at 30 solar farms in the US. Solar-native grassland habitat produced a three-fold increase in pollinator supply compared to pre-solar agricultural land.	Research paper	Walston et al., 2021

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ENHANCEMENT OPTIONS	KEY MESSAGES	PUBLICATION TYPE	REFERENCE
SOLAR			
(continued) **Establishing pollinator-friendly habitats and management practices**	Research paper on a longitudinal field study (2018–2022) to understand how insect communities respond to newly established habitat on solar energy facilities in agricultural landscapes. Results show the relatively rapid (<4 year) pollinator community responses to newly established solar-pollinator habitat.	Report	Wit & Biesmeijer, 2020
	Case study on the Shell Moerdijk solar farm and example of benefits to pollinators and surrounding agriculture.	Literature review and guidance	Wit & Biesmeijer, 2020
Bird and bat boxes, insect hotels, artificial hibernaculum and hollows.	A review of the efficacy of artificial structures for wildlife habitat creation and their potential use in solar farms. Reviews key benefits of artificial hibernaculum, artificial burrows, artificial hollows/nest boxes and bat boxes. It also includes management recommendations. Concludes that artificial habitat structures can potentially lessen impacts of solar farms through strategic landscape planning and an understanding of local biodiversity requirements to facilitate recolonisation.	Literature review and guidance	Boscarino-Gaetano et al., 2024
Revegetation to enhance biodiversity, while also reducing need for water to clean panels of dust, and potential cooling effects	Research paper which assesses the ability of eight native plant species to trap mobile sand and dust in Kuwait and the benefits for solar farms. Concludes that Haloxylon sp. has the greatest ability to trap mobile particles. Shows that the presence of some native plant species around solar farms can reduce the need to clear dust manually.	Research paper	Al-Dousari et al., 2020
	Study which monitored the microclimate, soil moisture, panel temperature, electricity generation and soil properties at a utility-scale solar facility. Results suggested that the compounding effect of photovoltaic arrays and vegetation may homogenise soil moisture distribution and provide greater soil temperature buffer against extreme temperatures. The additional benefits to pollinators, via the provision of pollinator habitats, is highlighted.	Research paper	Choi et al., 2023
	A regenerative guide to nature-positive solar farming with mitigation actions and biodiversity enhancement ideas, including suggestions of appropriate flora for the New England Tableland bioregion of New South Wales, Australia. Example of 37 ha planting of saltbush to suppress dust and cool panels with minimal maintenance requirements.	Guidance document	Community Power Agency, 2024
	Highlights that revegetating land underneath a solar installation can prevent loss of wildlife habitat, and that vegetation of a proper height can eliminate the need for dust suppression, and that there is potential for increased efficiency and longevity of PV panels due to the microclimatic cooling effects of vegetation.	Research paper	Macknick et al., 2013

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ENHANCEMENT OPTIONS	KEY MESSAGES	PUBLICATION TYPE	REFERENCE
SOLAR			
Co-benefit of re-established wildflower meadows for grazing and pollination services	Evaluated the monetary benefits of pollination services from installing honeybee hives in solar parks. Estimated that, if honeybee hives were installed in all existing solar parks within England, the pollination service benefits for pollinator dependent field crops, top fruits and soft fruit would have been £5.9 million in 2017.	Research paper	Armstrong et al., 2021
	Study showing that bumble bee density is driven by solar park management, size, shape and landscape context. Twice as many bumble bees were foraging and nesting inside solar parks managed as wildflower meadows, compared to those with only wildflower margins. Also, there were twice the number of foraging bumble bees surrounding large solar parks managed as meadows compared to smaller parks managed as turf grass.	Research paper	Blaydes et al., 2022
	Highlights the benefits of solar energy generation coupled with ecological restoration and/or pollinator habitat, which include pest regulation, carbon sequestration and storage, erosion prevention, habitat for species, maintenance of genetic diversity, and pollination. Also, the coexistence of grazing habitat for livestock may reduce the need for vegetation removal and maintenance.	Research paper	Hernandez et al., 2014; 2019
	Presents a concept for designing native seed mixtures to promote pollinators, especially wild bees, in solar parks. Provide an index for determining the value of native seed mixtures for wild bee enhancement and applies it as an example to several mixtures specifically designed for solar parks.	Research paper	Meyer et al., 2023
	Created the Solar Park Impacts on Ecosystem Services (SPIES) decision-support tool (DST). Evidence within the SPIES DST suggested that all management actions accessed should enhance habitats and biodiversity and pollination regulation. Most evidence relating to 'maintaining habitats and biodiversity' was associated with the management action of creating/maintaining buffer zones/ field margins/set-aside, while most evidence relating to 'pollination regulation' was associated with plant/maintain flower/nectar seed meadows.	Literature review / research paper/ tool	Randle-Boggis et al., 2020
Floatovoltaics reduce water evaporation and algal growth, improving water quality	Highlights that floatovoltaics have 11 potential techno-ecological outcomes and can reduce water evaporation and algae growth, can be integrated over hydroelectric reservoirs, and can improve water quality. Also uses an example to show that floatovoltaics can increase PV efficiency by lowering module temperature.	Research paper	Hernandez et al., 2019
	Describes benefits of floatovoltaics (i.e. minimise evaporation, reduce algae growth, cool water temperatures, and improve energy efficiency through evaporative cooling). Describes opportunities for floatovoltaic deployment, particularly the benefits of deployment on reservoirs.	Research paper	Hoffacker et al., 2017
	Uses a case study from California (USA) to quantify the evaporation savings, mitigation of aquatic weed growth and financial co-benefits from covering canals with solar panels. Found that the net present value (NPV) of over-canal solar exceeds conventional over-ground solar by 20% to 50%.	Research paper	McKuin et al., 2021

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ENHANCEMENT OPTIONS	KEY MESSAGES	PUBLICATION TYPE	REFERENCE
SOLAR			
(continued) **Floatovoltaics reduce water evaporation and algal growth, improving water quality**	Paper assessing potential ecological impacts of floating photovoltaics on lake biodiversity and ecosystem functioning. Concludes that impacts will be context-dependent, and that high floatovoltaic cover can limit light, wind speed and reduce water temperature, and that floatovoltaics have effects ranging from individual metabolic rates to ecosystem functioning.	Research paper	Nobre et al., 2023
Partnerships for enhanced biodiversity outcomes	Partnership between the Bee & Butterfly Habitat Fund and Lightsource bp Honeysuckle Solar project. Aims to increase and improve critical pollinator habitat for honey bees and monarch butterflies.	Website article	Honeysuckle Solar to host co-located pollinator habitat in partnership with the Bee & Butterfly Habitat Fund (2023)
	Protection of natural habitats. Collaboration between Ørsted and The Nature Conservancy (TNC) to protect almost 1,000 acres of native prairie in northeast Texas. This built on the Ørsted's ambition that all its renewable energy projects have net positive biodiversity impact from 2030 onward.	Website article	Ørsted and The Nature Conservancy to Protect Threatened Texas Prairie at Mockingbird Solar Center (2023)
	Collaboration between the Pollinator Habitat Aligned with Solar Energy (PHASE) study and Lightsource bp aiming to measure the ecological benefits of pollinator habitat at utility-scale solar projects, including Bellflower.	Website article	Researching the benefits of pollinator conservation at Bellflower Solar (2023)
	New solar developments are being designed to meet the RSPB's Fair to Nature Standard. RSPB advise on how Lightrock Power can go beyond biodiversity NG commitments for priority species and habitats.	Website article	RSPB partnership with Lightrock Power (2021)
	Partnership between Lightsource bp and Arkansas Monarch Conservation Partnership (AMCP) to provide habitat for migratory Monarch butterflies.	Website article	Solar farm, safe haven: Monarch butterflies to find crucial habitat at Conway Solar (2023)
	Partnership with Universidad de Córdoba and Universidad Autónoma de Madrid to determine appropriate biodiversity enhancement measures.	Website article	VELUX Group and BayWa r.e. solar PV (2024)
	Partnership between European Energy and the Danish Society for Nature Conservation (Danmarks Naturfredningsforening). For every 100 hectares of land that European Energy uses for a solar farm, five hectares of land will be purchased for nature. For each wind turbine installed, one hectare of land will be purchased for nature. The land purchase will be conducted in collaboration with The Danish Nature Fund (Den Danske Naturfond).	Website article	Denmark: Agreement for nature-friendly renewable projects (2024)
ONSHORE WIND			
Biodiversity enhancement – general	Examining regulations, incentives, and corporate practices influencing Swedish wind power companies in relation to biodiversity management at wind farms. Including opportunities and challenges and an RWE pilot project in a Nordic forest environment.	MSc Thesis	Svegborn, 2024

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ENHANCEMENT OPTIONS	KEY MESSAGES	PUBLICATION TYPE	REFERENCE
ONSHORE WIND			
Habitat restoration	Scottish Renewables publication showcasing more than £2.5 million of peatland restoration work carried out by three renewable energy companies at sites across the country.	Report	Wind power and peatland – enhancing unique habitats (2020)
Co-benefit of increasing vegetation physiological condition downstream	Positive effects on habitat condition and ecosystem function in the Gobi Desert resulting from wind dynamics downstream of turbines.	Research paper	Xu et al., 2019
'Green corridors' below transmission line	Analyses how 'green corridors' below transmission lines can be used to increase habitat connectivity and how they can aid in enhancing biodiversity when they are sustainably managed (in the European context). Includes a case study.	MSc Thesis	Swarnamaheswaran, 2023
Partnerships for enhanced biodiversity outcomes	Ørsted's partnership with Playa Lakes Joint Venture contribution will restore habitat for migratory birds and other wildlife while supporting community water management	Website article	Ørsted Partners with Playa Lakes Joint Venture to Restore and Preserve West Texas Wetlands (2023)
	Ørsted's US$ 2 million donation to The Conservation Fund and The Nature Conservancy (TNC) will support voluntary land conservation and restoration activities on up to 3,000 acres of tallgrass prairie habitat within the Kansas Flint Hills.	Website article	Ørsted Partners with The Conservation Fund and The Nature Conservancy to Protect and Restore Native Tallgrass Prairie near Sunflower Wind Farm (2023)
OFFSHORE WIND			
Biodiversity enhancement – General	An information hub for nature enhancement in offshore wind farms, projects in the North Sea, and practical information about suppliers, permits, and more.	Tool	The Rich North Sea Nature Enhancement Toolbox (2024)
	Report demonstrating available practices for shared use in offshore wind farms related to the nature transition (nature-inclusive design, biodiversity enhancement etc.,) food transition and energy transition.	Report	Advancing multi-use in offshore wind farms: Roadmap for the Dutch North Sea (2023)
Artificial reefs and reef effects	ECOncrete articulated concrete block mattresses were deployed at the Vineyard Wind 1 OWF in Massachusetts to protect submarine cables and create environmental conditions that encourage the growth of marine flora and fauna. These marine mattresses include a bio-enhanced mix, surface area and design – based on nature – optimised to create habitats for a wide range of marine organisms, thus increasing species richness, reducing invasive species dominance and increasing biodiversity. A $3 million fund has also been established at this farm to develop and demonstrate innovative methods and technologies to improve the protection of marine mammals and support regional monitoring efforts as the offshore wind industry in Massachusetts and the United States grows.	Website article	Avangrid use of ECOncrete cable mattresses (2024)

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ENHANCEMENT OPTIONS	KEY MESSAGES	PUBLICATION TYPE	REFERENCE
(continued) **Artificial reefs and reef effects**	Reviewed key benefits of artificial habitat structures and found many studies supporting the following key benefits of artificial reefs: aids in conservation, provides shelter, source of food, provides nurseries, enhances fisheries, restores degraded habitat, provides structural complexity and increases production of ecosystem. Assesses considerations for artificial reef planning, highlighting that the most important factor is the structural complexity of the artificial reef.	Literature review and guidance	Boscarino-Gaetano et al., 2024
	Provides a framework for selecting biodiversity enhancement options for different OWF locations, and forms a basis for the design of five offshore projects within the Rich North Sea Programme. Assesses six biodiversity enhancement measures for OWF, which include natural substrates deployment, reintroduction and facilitation of reef-building species, and artificial substrates deployment for artificial reefs on soft sediment or at scour protection.	Programme report	Bureau Waardenburg, 2020
	Quick scan of the potential to upscale positive effects of scour protection on benthic macrofauna and associated fish species. Found that total epibenthic species richness on scour protections may double when introducing scour protection at locations other than the current locations.	Research paper	Coolen et al., 2019
	Research paper finding increases in abundance of species associated with hard substrata after establishment of artificial structures (i.e. both OWFs and artificial reefs) in the marine environment. Literature indicated that scour protection meets the requirements to function as an AR, providing shelter, nursery, reproduction, and feeding opportunities.	Research paper	Glarou et al., 2020
	Reviewed 620 studies of artificial reef research. Found that research into more elaborate techniques is increasing, e.g. the use of remotely-operated submarines, organic indicators, isotopes and molecular biology. Concluded that the challenge is to develop robust management models.	Literature review	Lima et al., 2019
	Research paper investigating OWF foundations as artificial reefs. Found that catch rates of Atlantic Cod were highest around monopiles with rock protection. Monopiles with sandbag protection and jacket foundations attracted significantly less cod. Found that reef effects were spatially restricted.	Research paper	Werner et al., 2024
	Assessed the habitat-creation potential of offshore wind farms and suggests a number of enhancement options including scour protection acting as potential artificial reefs, use of synthetic fronds, gravel and boulders, creation of a large range of hydrodynamic niches within scour protection and careful matching of scour protection to habitats.	Research paper	Wilson & Elliott, 2009

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ENHANCEMENT OPTIONS	KEY MESSAGES	PUBLICATION TYPE	REFERENCE
OFFSHORE WIND			
Ecosystem restoration	European flat oyster (*Ostrea edulis L.*) reefs are a potential keystone habitat for the North Sea ecosystem but many factors have caused their disappearance. The ECOFRIEND project aimed to develop and study new methods to re-introduce and monitor flat oyster reefs and related biodiversity in offshore wind farms, in cooperation with the wind industry. Project aims included a proof-of-concept for active reintroduction of offshore flat oyster beds, to show whether there would be a viable population of flat oysters in an offshore wind farm. Monitoring showed the flat oyster population to be viable. Results have been disseminated to enable interested parties, such as the offshore industry, to use them for design, execution and monitoring of flat oyster restoration pilots in the offshore marine environment.	Project report	Bos et al., 2023b
	ReCoral by ØrstedTM is a project that sets out to discover whether offshore wind turbine foundations could provide additional habitat where corals could flourish. It is a proof-of-concept trial in partnership with the Penghu Marine Biology Research Center, and aims to support natural coral growth on the foundations of offshore wind turbines on the Greater Changhua offshore wind farms in Taiwan, by cultivating washed-up coral spawn and introducing viable larvae into mesh cages around turbine foundations.	Website article	Ørsted, 2024a
	The Humber Estuary in the UK (SAC and SPA) has been degraded by pollution and commercial development, leading to habitat loss. Ørsted are collaborating with Yorkshire Wildlife Trust and Lincolnshire Wildlife Trust to restore seagrass and salt marsh and introduce half a million native oysters to improve the health and resilience of the estuary's ecosystem.	Website article	Ørsted, 2024b
Creating refugial habitat free from trawling for fish	Using case studies, found a positive impact of wind farms on macrozoobenthos, concluding that this likely a result of the absence of bottom trawling. Benefits of an absence of trawling are discussed.	Research paper	Knorrn et al., 2024
	Discusses potential of offshore wind farms to act as no-trawling or sanctuary areas, as it is impossible to trawl close by turbines due to the safety zone preventing entanglement of fishing gear. Trawling will be prohibited or limited in these safety zones, so developments may act as no-trawling zones (NTZs), where fish will have higher survival rates.	Research paper	Langhamer, 2012
	Study suggests that apparent positive effects on fish abundance in an OWF may be due to a refugium effect as fishing is prohibited in the OWF. States that refugium effects have been demonstrated for even relatively small areas for the edible crab, pollock, cod and lobster.	Research paper	Stenberg et al., 2015

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