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Wind4Bio

Wind4Bio
Increasing the Social Acceptance of Wind Energy

ACTIVITY I.3

DI.3.1 Biodiversity risk management framework

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Framework for mitigating the biodiversity risks of wind farms in Wind4Bio territories

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Activity: A I.3

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Executive Summary

The presented report provides guidelines for setting a biodiversity risk management framework to mitigate the risks for biodiversity related to the deployment, operation and end-of-life phases of wind farms in Wind4Bio territories.

In this context,

- Section 1 will provide the activity's scope and objective and highlight its links to prior Wind4Bio activities, and the project's overall goals.
- Section 2 elaborates on sensitivity assessment regarding biodiversity in wind farms (e.g., identification of habitat types, flora and fauna and categorised by species, conservation status, and total population).
- Section 3 provides guidelines for assessing wind farm biodiversity impacts throughout their lifecycle, including construction, deployment, operation and maintenance of wind farms, while, ensuring a harmonious balance between renewable energy expansion and biodiversity conservation.
  and ensuring conservation of species, habitats, and ecosystems.
- Section 4 pinpoints suitable mitigation measures for each step of wind farm development to minimize potential negative impacts.
- Section 5 offers monitoring resources and procedures for assessing the success of any mitigation strategies that are put in place.

List of Abbreviations

AA: Appropriate Assessment
EC: European Commission
EEC: European Economic Community
EIA: Environmental Impact Assessment
EU: European Union
GBIF: Global Biodiversity Information Facility
GIS: Geographic Information System
GPS: Global Positioning System
GR: Greece
IUCN: International Union for Conservation of Nature'
LPI: Living Planet Index
LV: Latvia
NGO: Non-Governmental Organisation
OECMs: Other Effective area-based Conservation Measures
PA: Protected Areas
PL: Poland
PROMEA: Hellenic Society for the Promotion of Research and Development Methodologies
RES: Renewable Energy Sources
SEA: Strategic Environmental Assessment
SMART: Specific, Measurable, Achievable, Relevant, and Time-bound
TBC: The Biodiversity Consultancy
UPAT: University of Patras

1 Introduction

1.1 The Wind4Bio project

The transition of EU to climate neutrality requires a shift in its economic model, a focus on renewable energy sources and the phase out fossil fuels. In this context, wind energy offers, perhaps, the highest potential for scaling up the renewable energy production as it can be readily exploited throughout the EU. However, the deployment rate of new wind farms in EU and Wind4Bio countries is currently much slower than the one foreseen in the EU and national strategies.

In the context, Wind4Bio aims to address one of the primary barriers to the establishment of wind farms in partnership territories, namely public opposition to wind farms on the grounds of concerns related to the impact of wind farms on the local ecosystems and biodiversity in particular. To that end, the project will implement a multi - layered approach, directed to public authorities, the civil society and businesses in the wind energy value chain, engage and involve civil society in wind farm planning and monitoring and improve business practices in wind farm citing, operation and maintenance in order to harmonise biodiversity conservation, renewable energy expansion and wind energy policies.

1.2 Activity I.3

Activity description and partners' roles

University of Patras (UPAT, GR) will develop a framework for biodiversity risk management, also incorporating the results of Activities I.1 and I.2. WiseEuropa (PL), Green Liberty (LV), and PROMEA (GR) will evaluate the framework and provide feedback for improvements.

The biodiversity risk management framework, addressed to public administration and energy and environmental agencies, will deliver guidelines on how to:

i) Assess biodiversity sensitivity in wind farm sites,
ii) Identify the potential impact to biodiversity throughout wind farms' lifecycle,
iii) Pinpoint suitable mitigation measures,
iv) Propose tools and processes for assessing the impact of any mitigation measures that will be implemented.

Objective

Utilising the framework will allow potential adopters (public authorities and agencies) to detect, assess, and reduce risks to biodiversity associated with wind farms, also increasing the transparency of the process.

1.3 Key findings and recommendations from Activity A I.1

As part of the Activity I.1, UPAT, Green Liberty and WiseEuropa collected territorial evidence on: i) good practices (including tools, operating procedures, land rehabilitation plans) that mitigate the impact of wind farms to wildlife, ii) model examples regarding practices that have led to the harmonious coexistence between increased biodiversity protection and financially sustainable wind farm operations, iii) cases to avoid, where an inappropriate wind energy planning led to detrimental effects on biodiversity and iv) technologies (e.g. ornithological radars, bat detectors) and (v) technical characteristics (e.g. turbine blade profile, rotation speed, size) that can lower bird and other animal fatalities without a major impact on energy output. The survey revealed a gap in the utilization of state-of-the-art technical solutions for the management of biodiversity risks in wind farms, as well as a lack of monitoring and assessment processes. As a result, in the proposed framework, these considerations will be further utilised, notably when identifying and outlining mitigation strategies for dealing with biodiversity risks related to the placement and operation of wind farms.

1.4 Activity A I.2

Activity 1.2 involved a partners' site visit to Lafora, a Latvian wind park project notable for its environmental impact assessment (approved in 2021), which examined the proposed wind farm's impact on ornithofauna, bat populations, specially protected habitats, plant species, cultural and historical values, and landscapes. A particularly protected environment area and three other Natura 2000 areas surround the wind farm, but no specific mitigation measures are required. Experts in habitat identified two sites where the intended activity could conflict with conservation and preservation goals, and solutions to move the planned station and building site were discovered. Bat experts advise using bat mode and acoustic bat deterrents. Construction was scheduled to begin in June 2023, with wind turbines expected to be operational by mid-2024. The site visit provided participants with first-hand insight into a multi-stakeholder approach for wind farm deployment, enhancing practical knowledge and supporting on-going transformation processes to improve biodiversity risk management.

2 EU policy framework

The European Commission (EC) has established a number of procedures to minimise the impact of wind energy projects. These include:

- The Strategic Environmental Assessment (SEA)

The incorporation of environmental factors into policies, plans, and programs as well as looking at how they interact with social and economic factors are the primary goals of SEA. In this context, SEA also takes into account potential conflicts between wind energy projects and biodiversity preservation in the context of wind farms.

- The Environmental Impact Assessment (EIA)

Early screening of potential wind farm locations should involve EIA and Natura 2000 designated areas to identify potential risks. EIA is a tool to evaluate the environmental impacts of a wind farm project. EIAs ensure that project decision-makers consider the adverse impacts on biodiversity as early as feasible and work to avoid, mitigate, or counteract those effects.

- The Appropriate Assessment (AA), if the project affects ecosystems and species protected by the Natura 2000 network.

The AA assesses the impact of a plan or project on a Natura 2000 site, focusing on local species and habitats. It can be used along with the other environmental evaluations such as an EIA or a SEA. The assessment process involves gathering information on the plan or project, evaluating its impact on Natura 2000 sites, assessing potential adverse effects, and considering mitigation measures along with monitoring. The assessment often entails submitting an assessment report to the appropriate authorities, and if negative consequences are discovered, mitigation actions may be offered. The competent authority is responsible for determining the project's impact on the integrity of the site.

However, these procedures can often be ignored in practice, and poor quality or implementation is identified as a major barrier to the implementation of conservation strategies. In particular, the Wind4Bio countries are at times lagging behind in monitoring and evaluation mechanisms as well as in their use of existing technical solutions for mitigating the impact of wind farms on biodiversity (Activity 1.1). Additionally, a unified and up-to-date methodology for assessing the environmental and biodiversity impact of wind farms can be an issue.
As a case in point, according to Ornithologiki, a well-established environmental NGO for bird protection, the Greek Administration has yet to completely incorporate EU Directives for the protection of wild birds and ecology in Greek Law. In particular, while activities are not prohibited within protected areas, they

must be compatible with the conservation priorities of these regions. Therefore, before any activity within NATURA protected areas is approved, the consequences on the environment must be carefully considered. The authorities have consistently disregarded these criteria, approving projects despite their severe impacts on habitat and biodiversity. According to the existing spatial planning document (which is under revision the past years), a research on the impact of wind farms on birds is not legally required in Natura areas. Furthermore, a number of projects have been approved without appropriate consideration of the implications, as required by the European Habitats Directive. Overall, there are gaps in the present policy framework directly impacting the preservation of local biodiversity (Greece is a biodiversity hot spot), and a more detailed assessment of wind farms' impact on biodiversity is required.

In this context, the proposed framework provides guidelines for protecting biodiversity by delineating a step-by-step process to assess the potential biodiversity risks from the deployment of a wind farm to the identification and monitoring of mitigation options. The framework can help partners, stakeholders, local and national authorities make informed decisions, and balance the need for renewable energy with environmental protection, and meet EU biodiversity conservation goals. By incorporating a biodiversity risk assessment framework into the existing procedures like EIAs and therefore into decision-making processes, partners, local and national authorities in the EU can help ensure that wind farm development is carried out in an environmentally responsible and sustainable manner, in line with EU biodiversity conservation goals and regulations. Wildlife sensitivity maps can be consulted during this stage to aid in final location selection and support EIAs.
In accordance with Article 6(3) of the Habitat Directive 92/43/EEC, this framework can also be employed in the context of public engagement and public hearings for wind farm projects, providing a tool that the local communities can utilise to ensure the mitigation of biodiversity risks.

3 Conducting a sensitivity assessment

The first step to the adoption of any mitigation strategy is the assessment of the sensitivity of the local ecosystem (i.e., fauna and flora) to exogenous disruptions, such as the establishment of wind farms. In this regard, the framework offers targeted actions and measures to evaluate the ecosystem sensitivity in order to lay the groundwork for assessing the overall impact to local biodiversity and the identification of the appropriate risk mitigation measures.

In this context, the **wildlife / biodiversity sensitivity mapping** remains an essential tool for identifying and visually presenting areas of increased sensitivity, i.e., ecosystems with relatively low resilience to exogenous (including anthropogenic) changes. The information provided by the map (see Figure 1 for relevant examples) will subsequently form the basis of the wind farm impact assessment.

3.1 Wildlife / biodiversity sensitivity mapping

Central to the development of a biodiversity sensitivity map is the mapping of sensitive flora and fauna species, i.e., species facing threats to their population and habitats, in the area under investigation. These maps serve as the starting point for the impact assessment and mitigation strategies by showing the locations and risk level of the various species. In this context, wildlife sensitivity maps build upon available information on local biodiversity and utilise mathematical models and Geographical information Systems to provide a tool to support wind farm planning. In particular, wildlife sensitivity maps can be utilised during the planning stage to support the appropriate site selection and inform impact assessments.

The general steps involved in **creating a wildlife sensitivity map** are the following*:*

1. Determine map use and relevant ecosystem pressure

The initial step in developing a sensitivity map is to identify map use. This will determine the required resolution of the map, i.e., the size of the cells used in the map (Figure 1) and will determine the parameters that will be taken into account during the development process, including the relevant pressure on the ecosystem. In the context, of wind farm development the main pressures come from the space needed for the infrastructure required to operate the wind farm and link the farm to the electricity grid, and the need to develop to ensure access to the wind farm.

2. Prepare a risk analysis

An essential step in preparing a risk analysis is to identify local biodiversity risks in the area affected by planned wind farms. This involves identifying resident and migratory species sensitive to ecosystem changes, and assessing key information such as available food sources, trophic levels, species interaction nesting sites, and breeding patterns. It is also crucial to identify species with high conservation status, as these represent the highest biodiversity risks from exogenous interventions in the ecosystem. The vulnerability of local or migratory species must be considered for all life phases, including breeding, migration, and non-breeding periods. When wind turbines reach the end of their useful life, dismantling and removal of infrastructure should be considered and carried out in a sustainable manner.

To prepare the sensitivity map, it is essential to employ scientific data on sensitive species and habitats in the areas of interest. To this end, it is advisable to search sources like the EU Habitats Directive, Natura 2000, IUCN Red List or other lists. When datasets for the areas under investigation are spatially or otherwise incomplete, the use of relevant models can be used to estimate species distribution in these areas. This helps fill in gaps in our understanding of species distributions and aids in conservation planning efforts. Addressing data gaps and methodological flaws in a study can lead to greater advancements in future studies and improved mapping attempts.

3. Establish a sensitivity scoring system

The sensitivity score is a tool used to assess biodiversity risk in an area, aiding in the allocation of resources and prioritizing conservation efforts. It assigns a score to species based on their behaviour, habitat fragility, and conservation status. This score is developed using scientific data, expert knowledge, and ecological models. It considers factors like population size, reproductive rate, and vulnerability to environmental changes. Additionally, regular monitoring and reassessment of the sensitivity score can ensure that conservation strategies remain adaptive and effective in addressing emerging threats to biodiversity. To this end, conducting thorough research and analysis of each species' ecological requirements and vulnerability to threats can assist in this. Additionally, experts can use historical data and predictive models to assess the potential impact of human activities on the species and their habitats. By considering these factors, a comprehensive *sensitivity score system for each species* can be created to guide conservation strategies and ensure the most effective allocation of resources.

Through the utilisation of the sensitivity scoring system, sensitivity maps can also include a spatial resolution of species' sensitivity, categorizing core features as no-go areas for wind farm deployment and less sensitive secondary areas as potential development sites.

4. Develop the sensitivity map

Based on the identification of the vulnerable species impacted by the wind farm and the preparation and utilization of the sensitivity scoring system, one can proceed to the *development of a sensitivity map* that will encapsulate all the identified information and provide a visual representation of the local biodiversity risks. The final sensitivity map combines each species' individual sensitivity score into one.

An example of a sensitivity map is provided in Figure 1.

Morphology / behaviour / population dynamics score: (1=Low sensitivity, 2=medium sensitivity , 3=high sensitivity, 4=very high sensitivity).

Conservation score: (0=Low, 2=medium , 4=high, 6=very high).

SENSITIVITY SCORE: MEDIUM (3-8) HIGH (9-14) VERY HIGH (15-20)

(Any species scoring 3 or 4 for morphology / behaviour / population dynamics is automatically in HIGH category)

Species	Morphology	Behaviour	Population dynamics	Conservation status	Sensitivity Score
Species 1	3	1	1	0	5
Species 2	2	2	2	0	6
Species 3	4	2	1	6	13
Species 4	4	4	4	6	18

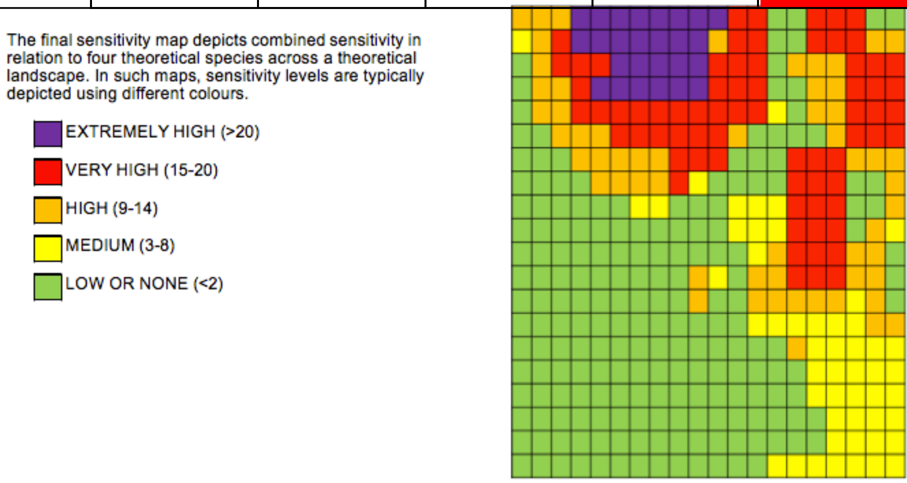

Figure 1 Example of a sensitivity map's first step (top) and final step (bottom) – [EC, Allinson et al, 2020]

The actual process of developing the sensitivity map comprises the following steps:

1) Identify the optimal mapping format and Geographic Information System (GIS) tool based on the requirements and specifications established in the previous steps
2) Prepare a grid with the appropriate spatial resolution, that will encapsulate the identified data on species' populations (also using relevant population distribution models)
3) Assess the sensitivity score (using the sensitivity scoring system) in each grid module to obtain the overall sensitivity map.

Overall, the most advanced treatment to present the map is through a web-platform. This approach is by far the most dynamic, enabling a more interactive and immersive experience. However, it should be noted that dynamic web platforms displaying interactive maps require considerable technical ability to create and maintain. This is therefore a costly and complex option.

5. Interpretation

The sensitivity score can provide a quantitative measure of the level of biodiversity risk in the area under investigation and constitutes an essential tool to identify the appropriate risk mitigation measures. In particular, including different sensitivity levels makes the identification of areas that require immediate attention or are associated with lower risks easier. In turn, this allows for a more efficient allocation of resources and prioritization of mitigation efforts. To facilitate the utilisation of the sensitivity map from different users, it is a good practice to include details on the methodology used to calculate the sensitivity scores, including any relevant data sources and algorithms, as supporting documentation. It should also be explained how the map was generated, including the software or other mapping tools that have been used.

3.2 Wildlife sensitivity mapping study cases

In 2010, Hellenic Ornithological Society identified and mapped sites in Greece (Figure 2), which have increased sensitivity, in terms of biodiversity concerns, to the establishment and operation of wind farms. The overall goal of this action was to provide valuable information and guidelines for sustainable wind energy projects, while minimizing potential negative impacts on bird populations.

In 2016, Vasilakis et al study's sensitivity map depicts the range, core area, and non-core territory of the cinereous vulture population (Figure 3). The map provided a spatially explicit resolution to an issue between wind energy development and vulture conservation as a framework for prioritizing conservation efforts. A unique conservation method for assessing large-scale wind energy development projects combines collision fatality models and spatial use models created from telemetry data.

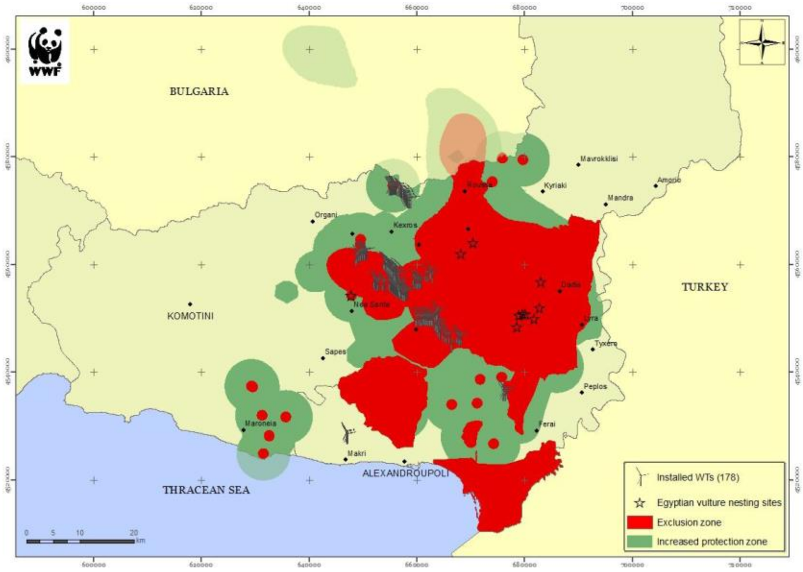

Figure 2 This map depicts the proposed [wind farm sites in Thrace]() (2013) showing the Exclusion Zone (in red), which includes areas of high and medium-high use by Black Vultures, radio-telemetry-based *high* use, National Parks, Loutra pine forest, Griffon Vulture colony, and *1000*-meter radius surrounding bird nesting sites and Black Stork nesting sites. It also shows the Increased Protection Zone (in green), which includes medium-low use areas, radio-telemetry-based *medium* use areas, and *5000*-meter radius surrounding bird nesting sites and Black Stork nesting sites

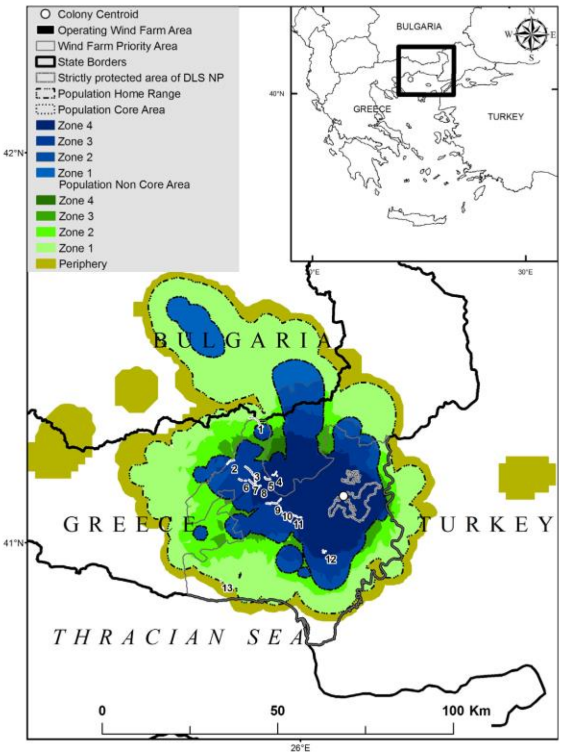

Figure 3 The cinereous vulture population sensitivity map depicts the range, core area, and non-core territory, which have been separated into four conservation zones along with the wind farm sites. The core area contains 53% of the wind farm priority area, ([Vasilakis et al, 2016]())

4 Identification of potential impacts to biodiversity

Following the sensitivity assessment it is important to identify the potential impact of wind farms on the local ecosystem, focusing on changes in population size or disruptions in the activities of wildlife species. Affected populations' genetic diversity, population size, and reproductive success rates should all be taken into account.

Identifying the potential impact (including, type of impact, extent and location) of the planned wind farm on local species populations and biodiversity is critical for selecting the appropriate mitigation measures. To this end, it is important to have a good understanding of the spatial distribution of populations of vulnerable species (including migratory species). This can be accomplished by looking at ecological pathways, the migration patterns of important species, as well as breeding grounds and foraging grounds. Furthermore, using lessons learned from other industries can improve risk assessments and the effectiveness of mitigation methods.

There are three main types of wind farm impacts: habitat-based, collision, and population-related. Habitat-based impacts involve the alteration or destruction of habitats, leading to the loss of nesting sites, feeding areas, and breeding grounds for vulnerable species. Collision impacts occur when birds or bats collide with wind turbine blades, resulting in injury or death. Impacts on population refer to the potential decline in population numbers of vulnerable species not only by habitat loss, disturbance, or increased mortality rates but also by other parameters such as each species' resilience or other sources of disturbance or mortality (such as climate change). Understanding these impacts is essential for assessing the overall ecological effects of wind farms and implementing effective mitigation strategies. Studying the cumulative impacts of wind farms and other factors impacting the ecosystem is also essential for understanding long-term consequences on biodiversity and ecosystem dynamics.

4.1 Loss of natural habitat

Understanding animal behaviour in response to wind energy projects and their infrastructure is crucial for estimating habitat-related risks. The impact of wind energy installations on species' habitats depends on their location, use of the landscape, and response to ecosystem changes. Poorly sited projects can lead to significant habitat reduction, exacerbated by supporting infrastructure like access roads and electrical cables. A dense concentration of wind turbines can increase habitat fragmentation, inhibit species' mobility, and have a significant cumulative impact on species' populations when combined with other activities.

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The *direct* habitat damage caused by wind energy infrastructure is typically limited. The roads required to build and maintain wind turbines cause the majority of permanent habitat loss. As a result, projects that use existing roads generally have a lower footprint than projects that require new roadways. The *functional* habitat loss, or displacement, that takes place when animals avoid using otherwise adequate habitat near wind energy infrastructure might often be more substantial than direct habitat loss from road and installation construction. The presence of people, loud construction noises, increased car traffic, or even the sound of turbines can all bother animals, causing them to move away. If animals associate certain infrastructure components with danger, they can also be driven away. Habitat-based impacts can have population-level consequences if habitat loss reduces breeding success and survival in the afflicted population, particularly in the case of vulnerable species with limited species range.

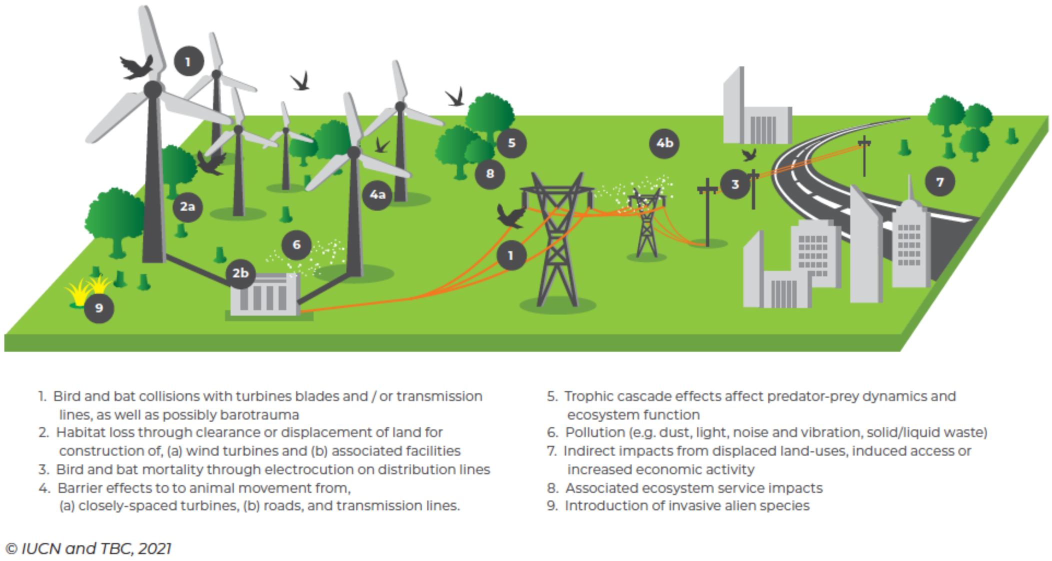

Figure 4 Onshore wind development's potential impact on biodiversity and associated ecosystem services (IUCN and TBC, 2021)

For example, some species actively avoid roads, which results in a more pronounced effective habitat loss and segmentation [1]. As a case in point, studies show that the effective habitat of black kites in Portugal was reduced between 3 and 14%[2]. Bats can also be impacted in the same way, although this is also dependent on the specific species as some actively avoid them while others are drawn to them, especially while looking for food. Bats may also be impacted due to the loss of roosting and foraging areas caused by the development of a road network to provide access to wind farms. Again, the impact on bats' behaviour patterns and activities may vary since species that prefer to forage along forest margins may find new habitats and ecological niches. Land mammals can also exhibit variable degrees of avoidance in their reactions to wind farms [3]. As an example, it has been observed that wolves in Portugal actively avoid wind farms, which has considerably altered the area available to them [4].

To assess potential impacts on wildlife, experts should conduct site visits before construction on a project to carry out a thorough field investigation to determine the species' range, abundance, habit, daily movements, and seasonal or cyclical migration. This pre-construction study can establish a baseline for determining the influence of wind energy projects on individual species' utilization of the area and can be subsequently employed for before-and-after comparisons of project sites and control sites. To account for potential reactions, various metrics are used, such as telemetry or GPS monitoring devices, and massive field surveys.

To identify and assess the loss of natural habitat, the following steps can be undertaken.

- **Establish the metrics needed to assess the impact on habitat**

Assessment of habitat impact requires a variety of metrics to account for the range of potential responses, in contrast to collision impacts, which are measured in terms of fatalities. These metrics may include:

- The (estimated) use of habitat (foraging, cover, nesting, escape or other life history traits).
- An estimation of changes in animal quantity and distribution.
- Changes in the behaviour of species in the area under investigation.
- Changes in habitat quality, such as alterations in vegetation composition or water quality.
- Additionally, the assessment should also take into account any potential indirect impacts on the habitat, such as changes in prey availability or disruption of ecological processes.

In order to develop a set of metrics to assess the impact of the proposed wind farms on the surrounding ecosystem it is essential to conduct thorough ecological surveys before and after the construction of the wind farms. These surveys should include monitoring species abundance, distribution, and behaviour, as well as collecting data on habitat quality parameters.

To that purpose, the use of relevant research papers is also expected to be highly beneficial in predicting the potential influence of the wind farm's development and operation on the surrounding ecosystem. These can provide important insights into the potential changes in biodiversity, habitat loss, and migratory pattern disturbance caused by the wind farm. They can also assist in the identification of mitigation measures and strategies to reduce any detrimental effects on the local ecosystem. By comparing the pre- and post-construction data, scientists can identify any significant changes in the ecosystem and determine the specific impacts of the wind farms on the surrounding habitat. This comprehensive approach will provide a holistic understanding to the relevant stakeholders of how the proposed wind farms may affect the ecosystem and guide future conservation efforts.

- **Determine the barrier effects for different species**

Barrier effects refer to the disruption of natural movements, such as foraging or migratory flights, leading to habitat fragmentation and increased energy demands. These effects can disrupt wildlife's natural patterns, forcing them to take longer and more energy-consuming routes, thereby negatively impacting their health and reproductive success. Additionally, barrier effects can lead to population isolation, reducing gene flow, and increasing the risk of local extinctions. Multiple wind farms in the same area may create obstacles for bird species, particularly migrating birds, which often fly in large groups along predetermined paths, causing casualties, wasting vital energy reserves, and leading them to abandon rest stops. Migrating raptors, for example, appear to change their flight paths to avoid new wind farms.

To determine the barrier effects for different species during construction and operation, it is crucial to:

- Use environmental impact assessments available for the area in question preferably studies on the species' habitats, migration patterns, and behaviour. If there is no available impact assessment, it is recommended to conduct one.
- Engage with field experts, such as ecologists or wildlife biologists, who will be able to provide consultation on the likely impact of wind farm on the local species.

4.2 Collision impacts

Wind turbines pose a serious hazard to wildlife, including birds, such as vultures, bustards, cranes, and migratory birds, which may collide with them and suffer severe injuries or even die**.** Wind turbine collisions have been a source of concern for birds (especially raptors) since the early 1990s [5], and for bats since the early 2000s [6]. Additionally, poorly designed *low- and medium-voltage lines*, required for the connection of the wind farm to the electricity grid, pose a major hazard to birds, particularly raptors. Bats, particularly those adapted to foraging insects in open spaces, are also at risk of collision with turbines. Without proper mitigation, collisions can result in significant losses in local bat populations, disrupting the ecological balance and impacting pollination and seed dispersal processes. Therefore, implementing effective mitigation strategies is crucial to minimize the negative impact of turbine crashes on bat populations and maintain a healthy environment.

Bird mortality from wind turbines can be estimated using various techniques, including:

- Using selection criteria for the prepared studies, which involve selecting only those that meet specific criteria such as the location and size of the wind turbine projects, as well as the type of bird species present in the area, in order to improve the predictive ability of these studies.
- Identifying trends and patterns in bird fatality rates and behaviour in relation to wind farms by conducting systematic reviews of the literature. This involves systematically searching and evaluating all relevant published studies on bird mortality from wind turbines to provide a comprehensive overview of the available evidence.
- Identifying correlations of mortality with specific turbine designs or placement strategies that leads to targeted interventions to reduce bird fatalities.
- Implementing monitoring programs to track bird behaviour and mortality rates near wind energy facilities and provide real-time data on the effectiveness of mitigation measures. This data can help identify any potential risks or patterns that may arise, allowing for timely adjustments to be made to minimize bird fatalities.
- Using predictive models can also help in identifying high-risk areas for bird collisions, allowing for targeted mitigation efforts.
- Collaborating with ornithologists and ecologists can provide valuable insights and expertise in understanding bird behaviour and migration patterns. This collaboration can lead to the implementation of effective measures such as adjusting turbine placement or implementing bird-friendly lighting systems to minimize bird collisions.
- Assessing the effectiveness of bird deterrent technologies, such as noise-emitting devices or visual markers, can also be studied through the analysis of bird fatalities near wind farms. This information can help determine which deterrent methods are most effective in reducing bird collisions and guide future conservation strategies for both wind energy and bird populations.

4.3 Population impacts

The impact on wildlife population might vary based on the species' *resilience* as well as the *size* and *dispersion* of its population. Because of their high reproduction rates or adaptation to new settings, certain species may recover fast following collisions or habitat loss. On the other hand, species with low reproductive rates or specialized habitat requirements may struggle to bounce back from population declines or habitat destruction. Additionally, factors such as competition for resources and predation pressure can also influence the ability of a species to recover from disturbances.
To effectively analyse the overall impact of wind farms on species populations, it is also necessary to examine the cumulative consequences of wind farms with

other sources of mortality, such as habitat loss due to other reasons or climate change. These additional sources of mortality can further exacerbate the challenges faced by vulnerable species. For example, if a species is already experiencing habitat loss due to climate change, the presence of wind farms could accelerate their population decline and make it even more difficult for them to bounce back.

In conclusion, assessing the impact of wind energy projects at a population level involves evaluating collision and habitat-related consequences, population dynamics, and other factors, not directly related to wind farms, that can lead to cumulative population impacts. Comprehensive monitoring and research efforts are thus necessary to inform decision-making and ensure sustainable development of wind energy while minimizing the negative impact on wildlife populations.

4.4 Expanding on the effects of offshore wind farms

All impacts discussed in the preceding sections apply to marine life as well. Offshore wind projects can pose significant threats to marine species, primarily through disrupting their natural habitats, breeding behaviours, and migration patterns [7]. These disruptions can have long-term effects on population dynamics. For example, the construction and operation of offshore wind farms can create underwater noise that can interfere with the communication and navigation abilities of marine species. This can lead to increased stress levels and decreased reproductive success for these animals, and therefore lead to declining populations. Additionally, collision impacts can occur when marine animals such as dolphins or seals collide with wind turbine structures, leading to potential injury or death. Understanding these various impacts is crucial for effective conservation and management of both terrestrial and marine ecosystems affected by wind farms.

More specifically, offshore wind farms can impact marine wildlife in the following ways:

- Noise and vibrations from wind turbines can affect their communication and navigation ability.
- Habitat damage, displacement of certain species, and increased pollution due to the construction of wind farms can affect marine animals' health and wellbeing.
- The presence of artificial reefs can alter habitats, prey, and food webs, increasing biodiversity and attracting larger predatory species.

- Operational noise and vibrations from wind turbines can cause electromagnetic noise, potentially disrupting navigation and affecting the ability of marine organisms to communicate and navigate.
- Increased vessel traffic from maintenance operations can lead to changes in prey behaviour, impacting the entire marine food chain and affecting predator species abundance and distribution. Noise generated by vessel traffic can also cause stress and disturbance to marine mammals, affecting their feeding and reproductive behaviours.
- Towards the end of life of wind farms, the debris generated from the demolition process can disrupt feeding grounds and breeding areas. Therefore it should be considered and carried out in a sustainable manner.

Partners and potential stakeholders of an offshore wind project can seek assistance in identifying the impacts on the marine life for the specific area by consulting with experts in marine biology and conducting thorough EIAs. These assessments can help identify potential risks and develop mitigation strategies to minimize harm to terrestrial and marine species. Additionally, collaboration with local communities and environmental organizations can provide valuable insights and ensure that the concerns of all stakeholders are taken into account during the planning and implementation of offshore wind projects.

5 Mitigation measures

Building upon sensitivity mapping and the biodiversity impact analysis, the identification of locally placed, case-sensitive mitigation measures represents the third step in addressing biodiversity risks related to wind farms. This includes both horizontal principles to be followed in all cases of wind farm planning, as well as more specific mitigation measures to be implemented for each stage of the wind farm case.

5.1 Horizontal measures

To minimize the impact of wind farms on sensitive species, several horizontal priorities have been identified.

Plan early and utilise biodiversity sensitivity maps and risk screening

Early planning and the use of biodiversity sensitivity maps and risk screening are crucial for identifying areas to avoid based on sensitive biodiversity features. This approach helps to identify important species and threatened ecosystems within potential wind farm sites, compare potential threats, and estimate biodiversity sensitivity. By utilizing biodiversity sensitivity maps and conducting risk screening, decision-makers can make informed choices about wind farm site selection. This approach allows for the identification of areas with minimal impact on sensitive biodiversity features, ensuring the preservation of important ecosystems. Additionally, risk screening provides valuable insights into the potential threats posed by wind farm development, allowing for effective mitigation measures to be implemented.

Select a site with low biodiversity sensitivity

Selecting areas with low sensitive, such as agricultural land, is crucial for maintaining healthy ecosystems. This approach preserves high biodiversity sites (areas where a wide variety of species), improving soil fertility, pollination, and natural pest control and promotes ecosystem resilience and ensures the ecological balance of sensitive areas. In principle, adjustments to infrastructure siting and operational planning are cost-effective and easier to implement compared to post-construction mitigation measures. Official land use plans prepared by government agencies or development banks can facilitate the site selection and minimize the impact on biodiversity and ecosystems.

Establish a mitigation hierarchy

Mitigation hierarchy is a tool used in wind farms planning to reduce biodiversity loss by identifying potential ecological impacts and implement mitigation measures. If biodiversity loss cannot be avoided, plans are made to enhance or offset the loss. The implementation process is iterative, incorporating feedback on the impact of wind farms and ultimately leading to changes in their operation.

Mitigation hierarchy consists of the following steps: complete avoidance, minimization, rehabilitation/restoration, offsetting and compensation. These steps work together to ensure that the negative impacts of wind farm projects are mitigated and that the overall health of the ecosystem is maintained or improved. More specifically the sequence of the mitigation hierarchy is the following:

1. **Avoidance** refers to the identification and selection of alternative sites for wind farm projects that have minimal ecological impact. Avoidance strategies in wind farm development help to reduce biodiversity risks by identifying and avoiding high biodiversity areas and also minimise potential conflicts with local communities and stakeholders. In this context, territorial plans that pinpoint areas with increased biodiversity can be highly helpful and should be utilised when available. Furthermore, environmental assessments and collaboration with conservation organizations can be useful tools to identify priority areas for wind energy development while preserving biodiversity.

2. **Minimisation of risks**: Minimisation refers to taking active steps to reduce the negative impacts of wind farm projects. To minimize biodiversity risks in wind farm projects, it is essential to implement measures such as temporarily shutdown of wind farms on demand, noise reduction technologies, selecting suitable turbine locations, using advanced technology, and employ monitoring programs. Buffer zones around the wind farm can minimize disturbance to sensitive habitats, while reforestation or habitat restoration projects can offset potential losses of biodiversity. Bird-friendly designs in wind turbines can also reduce bird collisions and protect avian species.

Minimising techniques and technologies

The use of advanced technology such as the employment of *"early warning systems"* like ornithological radars, video surveillance systems, thermal cameras, and bio-acoustic monitoring systems (e.g. bat detectors) is an important priority during wind farm operation. These systems, combined with traditional data collection methods (e.g., optical observations), can minimize impact on birds and improve biodiversity data on space use within a wind farm site during the planning stage. A proactive strategy to reduce wind farm impact on priority species is *turbine-timed shutdown*, which makes sure turbines are not in operation when birds are in the vicinity. This proactive strategy aids in the conservation and protection efforts and, if properly applied, may have little effect on potential energy output. Environmental impact studies and assessments can offer insightful information on the particular requirements and behaviours of priority species in the area, which can be used to design specialized mitigation plans. Temporary *shutdown on-demand* can be observed, automated, or a mix of the two. Observer-led shutdowns allow skilled workers to observe and make decisions in real time, whereas automated short shutdown systems use modern technology to detect possible risks and automatically activate a temporary shutdown without human interaction. Combining these approaches can result in a complete and efficient system that reduces the impact on priority species while maintaining the overall efficiency of wind farms. *Increasing turbine start-up speeds and using acoustic deterrents* have been shown to reduce bat fatalities. Increased turbine speeds allow bats to detect and avoid rotating blades, while acoustic deterrents that emit unpleasant high-frequency sounds can further minimise the risk of collision. Moreover, technologies like thermal imaging cameras provide real-time monitoring and detection, promoting the coexistence of wind energy and bat populations.

3. **Rehabilitation/restoration** involves restoring any areas that have been disturbed or damaged during the construction process in order to mitigate the effects of wind farms on local ecosystems and wildlife populations. Re-establishing vegetation or wildlife habitats, constructing animal corridors, reforestation, wetland restoration, and reintroduction of native species are all important steps toward restoring the natural balance and performance of ecosystems. Through the adoption of restoration and conservation measures as well as the development of monitoring programs, these initiatives can improve water quality, reduce soil erosion, and offer critical habitat for a range of plant and animal species. In this way, these measures support a more balanced and sustainable environment, allowing for the coexistence of renewable energy production and biodiversity conservation. Furthermore, educating local communities about the importance of environment restoration and conservation can foster a sense of stewardship and encourage sustainable practices for future generations.

4. **Offsets** are a mechanism used to counterbalance or neutralize the environmental effects caused by the development and operation of wind energy projects. When all other options for preventing, resolving, or mitigating impacts on biodiversity have been exhausted, offsetting is employed to balance off any remaining negative effects by boosting biodiversity in other areas. The objective of biodiversity offsetting is to accomplish a quantifiable no-net-loss and, ideally, a net-gain of native biodiversity in a comparable way (i.e., the same sort of biodiversity is lost and replaced). They might involve activities such as habitat restoration, or investment in renewable energy projects *in other areas*. By implementing offsets, wind energy stakeholders aim to minimise their overall ecological

footprint and contribute to the conservation and preservation of natural resources. Long-term monitoring and management of these offsets are crucial for their effectiveness.

5. **Compensation** strategies are intended to compensate for biodiversity loss caused by wind farms by encouraging conservation and sustainable use of natural resources. These actions include the creation of protected areas, biodiversity action plans, and financial support for conservation efforts. They could also entail replacing wind farms' devastated ecosystems with new ones, such marshes or woods. For long-term conservation efforts to be successful, on-going monitoring and assessment are essential.

5.2 Utilise effective mitigation strategies

During *project design*, effective strategies to avoid and minimise the impacts of wind farms on biodiversity include the following:

- Using underground electricity wires when possible or placing them in a way that they do not pass through high biodiversity areas
- Effecting changes in the siting of the wind farm, including modifications in the arrangement of turbines to reduce the possibility of collision.
- Using bird diverters to mark transmission lines which has been proven to significantly curtail bird collisions.
- Utilising distribution lines that are insulated to reduce electrocution risks for birds.

During *construction*:

- Avoiding construction work during key breeding and migratory periods.
- Employing tight construction procedures such as acoustic monitoring, soft beginnings, and acoustic deterrent measures, which can help to decrease noise impacts on offshore constructions.
- New risk-mitigation strategies and technology have the potential to lessen risks associated with wind installations. For example, the use of advanced radar systems can detect bird movements and automatically shut down turbines when birds are in close proximity. Additionally, implementing bird-friendly lighting designs can help to reduce collisions with structures during night-time hours.

During *operation*:

- Using fine-tuned protocols for the temporary shutdown of wind turbines when necessary. These can be based on detection technologies (e.g., radars), which will allow the short-term shut down of the turbines thereby minimising the collision risks while only marginally affecting the efficiency of the wind turbine.

- Employing measures to prevent bird collisions by increasing the overall visibility of turbine blades to birds (e.g., through painting the turbine's blades) have proven effective.
- Temporarily stopping the operation of turbines during low wind speeds has been shown to reduce bat collision risk without a significant impact on energy generation.
- Acoustic deterrents, which emit high-frequency sounds that are unpleasant for certain animals, can be effective in preventing them approaching the wind farm area. However, their effectiveness depends on the species and their sensitivity to sound. It also contributes to the reduction of the effective habitat.

Integrating such measures into wind farm design is generally straightforward and cost-effective.

5.2.1 Key mitigating strategies in each step of wind farm development

Project step	Threats	Mitigation strategies	Indicatives examples
Project design	Ill-designed wind farms, (including, supporting infrastructure such as access roads and powerlines) can result to severe habitat loss Densely built wind turbines can increase collision fatalities, fragment habitat, create obstacles to species movement, and potentially, along with other factors, have considerable cumulative impact on the local wildlife.	Altering (i.e., micro-siting) the project infrastructure's design to avoid sensitive locations. Wind farm developers can determine micro-siting locations using computer models that take into account wind resource, topography, and ecologically sensitive areas. Power lines can be rerouted or placed underground to avoid collisions and prevent barrier effects. Carefully selecting the location of wind turbines and establishing wildlife corridors	Ref [8], [9], [10], [11]

	Wind turbine placed near sensitive breeding sites, migration corridors, and high biodiversity sites can have a significant impact on wildlife and biodiversity.	Changing site selection through the use of local sensitivity maps and improving wind farm design (see micro-siting) to further reduce the impact to wildlife Adjusting the timeline of survey activities during site characterisation to not coincide with sensitive periods (e.g., breeding period) Utilising wind farm components that have been designed to mitigate impact on biodiversity (e.g., quiet foundations)	Ref [12], [13]
Construction	Disturbing wildlife during sensitive periods	Limiting construction activities and any other activity that might have an impact on animal behaviour during sensitive periods for the wildlife	Ref [14]
	Emitting emissions and pollutants, causing noise and light pollution	Abatement controls to reduce emissions and pollutants (noise, erosion, waste) created during construction Improved planning (including managing vessel movements and minimizing lighting in construction and installation projects) that will limit the	Ref [15]

		environmental impact of construction operations.	
	Reducing effective habitat during construction	Once wind turbines have completed their cycle, it is crucial to restore the site (to the degree possible) by using native flora species. Restore marine habitats (including coastal areas) that have been severely impacted by the construction of the offshore wind farm.	Ref [16]
Operation	Bird/bat collision with wind turbines or other wind farm infrastructure Electrocution	Temporary shutdown on demand to minimise collision risk Use of Bird Flight Diverters or other similar tools on transmission lines to reduce collision risk Painting wind turbine blades to increase their visibility Changing blade profile	Ref [17], [18]

	Displacement of wildlife due to the operation of the wind farm	Utilising abatement controls such as limiting movement of vessels and vehicles when vulnerable species are present Investing in habitat restoration efforts to create alternative habitats for displaced species, ensuring their survival and maintaining biodiversity in the area.	Ref [15], [19], [20]
End-of-life	Disturbance of wildlife during sensitive periods	The management of end-of-life infrastructure should be done sustainably in order to prevent upsetting animals during vulnerable periods.	Ref [21]
	Generating emissions waste and other pollutants	The management of end-of-life infrastructure should entail the use of advanced technologies and practices (such as robotic dismantling and recycling processes) in order to minimize harmful substances (i.e. chemicals such as lubricants, hydraulic fluids, and coolants used in the operation of the wind turbines or rare earth metals used	Ref [22], [23]

		in the production of magnets and electronic components, which can pose risks if not handled and disposed of correctly) release into the environment. Improved planning and implementation of the wind farm end-of-life phase (such as promoting the use of fencing, regulating vehicle speeds to reduce noise pollution).	
	Loss of fauna and flora	Restoration of native vegetation, to the greatest extent possible once wind turbines approach the end of their useful lives Infrastructure should be maintained if it benefits biodiversity and ecosystem services, such as the reef effect in the case of offshore wind turbines	Ref [24], [25]

5.2.2 Case study: enhance wind farm sustainability

The 2021 study by Kati et al [26] tackles the issue of compromising biodiversity and the use of Renewable Energy Sources (RES) to address climate change. In this context the study proposes a revolutionary approach to spatial design that improves the sustainability of wind farms in Greece, where there has been a lot of dispute between conservation and wind energy farm development. Priority is given to investments in the most dispersed zones outside of the Natura 2000 network of protected areas. The results show that this approach supports 1.5 times as much wind energy production as the 2030 national goal while it ensures protection of habitats and species. The analysis stresses how crucial it is to move environmental policy closer together with biodiversity conservation and zero net land take. Innovative solutions that address both energy demands and environmental concerns can be facilitated through cooperation between conservation organizations, governmental organizations, and wind energy providers. Wind farms can also help maintain or restore biodiversity within the infrastructure matrix farms, for example in the case of offshore wind farms by providing habitat for benthic habitats, fish, and marine mammals [27,28,29].

6 Monitoring the implementation of mitigation measures

Monitoring the impact of the implemented mitigation measures is highly important as it allows: i) the evaluation of the various implemented mitigation measures and the improvement of the overall mitigation strategies in other territories, and ii) the adoption of additional measures if required. Monitoring can take place through the employment of a combination of suitable tools and processes by the responsible authorities. As a result, it is essential to establish monitoring processes and tools that will streamline the monitoring of the mitigation measures.

6.1 Monitoring processes

The monitoring program should outline its aims, evaluate conservation operations on key species and habitats, and consider risks and obligations. It should also provide a timeline for data collection and report creation, considering budgetary limits and available resources [30]. Key parameters for establishing a solid monitoring framework include understanding the reasons behind monitoring, identifying indicators for accurate progress measurement, determining monitoring locations, scheduling, stakeholders, and resources needed for monitoring.

The following steps should be taken to successfully monitor and analyse biodiversity mitigation strategies for wind farms:

1. Understand the mitigation plan and its specific measures to protect local wildlife and ecosystems.
2. Establish clear and measurable objectives for monitoring and identify key stakeholders, such as developers, environmental agencies, local communities, and conservation organizations.
3. Develop a detailed monitoring plan by specifying the monitoring parameters, the data collection methods, the sampling design, the data analysis, and the reporting schedule.
4. Collaborate with experts, ecologists and biologists, to ensure scientifically sound data collection and analysis.
5. Implement monitoring activities according to the plan, set up a robust data management system, analyse and report data, adapt mitigation measures if necessary, comply with environmental regulations, maintain open communication with stakeholders, and continuously evaluate the monitoring process.

The monitoring program's capacity to advance understanding of the biodiversity indicators is the framework's final element. Project data should be archived in open-source repositories such as GBIF or through data centres to ensure transparent data management and to serve as a resource for future programs. Researchers and environmentalists can collaborate and improve on past discoveries, resulting in a more thorough understanding of biodiversity trends. Furthermore, the availability of historical data encourages accountability and enables independent verification of results, which increases the credibility of monitoring programs.

The work of Dalton et al. (2023) [30] can be referred as an example of framework and it provides a comprehensive approach to monitoring biodiversity, addressing key aspects such as species richness, population trends, habitat quality, and threats to ecosystem integrity. The framework ensures that managers have a holistic understanding of the conservation area's health and can make informed decisions to protect and enhance biodiversity.

6.2 Monitoring tools

Biodiversity indices are a crucial tool for risk management in wind farms, providing a comprehensive assessment of the ecological health of an area surrounding wind farms. They help identify potential impacts on different species and habitats, enabling targeted conservation efforts and evaluating the effectiveness of mitigation measures to minimize biodiversity loss due to wind farm development. There are over 60 indices in ecology that calculate proportionate abundances, taking into account factors such as species richness, evenness, and dominance. By using multiple indices, researchers can obtain a more accurate representation of the overall ecological health of an ecosystem. These indices can also inform conservation efforts and guide sustainable development practices to minimize the negative impacts of wind farm development on local ecosystems.
There are two primary categories of indices: *information statistic indices* (such as Shannon Weiner index), which measure the diversity and evenness of species within an ecosystem and *dominance indices* (such as Simpson index) that focus on the prevalence of the dominant species. By considering both types of indices, researchers can gain a comprehensive understanding of biodiversity patterns and make informed decisions for conservation and sustainable development efforts.

Biodiversity indicators
Biodiversity indicators, as defined by the Convention on Biological Diversity, encompass more than just species populations and ecosystem systems. They also

involve efforts such as protected areas and species harvesting regulation to ensure biodiversity conservation and sustainable use. They help measure pressures, threats, species health, conservation responses, and benefits to people. They can be used to influence local choices and report on national environmental policy and conservation initiatives.
The SMART (specific, measurable, achievable, relevant, and time-bound) principles are a framework for selecting indicators for biodiversity conservation programs. It emphasizes that indicators should be specific to the program's goals, measurable, realistically achievable for monitoring, relevant for decision-makers, and contains time-bound elements for periodic interpretation. Monitoring programs should also include habitat assessments, as habitat conditions may be linked to key species performance. The selection of indicators depends on the scope of biodiversity conservation targets and legal reporting requirements. Monitoring in Protected Areas (PA) and Other Effective area-based Conservation Measures (OECMs) often involves measuring parameters like species richness, abundance, occurrence, or health. Monitoring proxy variables (indirect parameters such as measuring habitat quality, ecosystem function, and genetic diversity) can simplify management objectives, but it can result in reduced precision, uneven reactivity to actual change, and ecological oversimplification. For example, the Living Planet Index (LPI) measures trends in the relative abundance of wild vertebrate populations, where a population is defined as a single species in a specific area.

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