



# REDUCING THE BIODIVERSITY IMPACTS OF ONSHORE AND OFFSHORE WIND FARMS



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# Foreword

In order to contribute to combatting climate change and limit its – already visible – consequences on our societies, numerous countries have committed to reducing their greenhouse gas emissions or even achieving carbon neutrality. France is one of those countries, having set itself such objectives by 2050. To respond to this aim and ensure long-term access to energy resources, a strategy is required: more energy-sober and decarbonized practices.

The IUCN French Committee supports the development of renewable energies as a means of mitigating climate change and securing French energy supplies. While this energy transition needs to accelerate in the next few years, the French Committee nevertheless calls for vigilance. The greatest precaution is required regarding biodiversity issues, which need to be systematically taken into consideration in the planning and development of each project. The deployment of renewable energies, as with any local development, can have significant impacts on fauna and flora, natural habitats and associated ecological functions and ecosystem services. Yet combatting climate change only makes sense if it is combined with the preservation and restoration of natural habitats. Indeed, the surest ways to mitigate and adapt to climate change are healthy ecosystems.

With the support of the French Agency for Ecological Transition (ADEME), French Ministry for Ecological Transition, Biodiversity and International Negotiations on Climate and Nature, AXA Foundation for Human Progress, Fondation Crédit Mutuel Alliance Fédérale and ENGIE Green France, the IUCN French Committee and its network of members and experts actively facilitates dialogue and knowledge-sharing between the various stakeholders involved in energy transition and nature conservation.

This guide is part of that process. By gathering concrete feedback on experience in the light of scientific knowledge, it is intended both to bear witness and to advocate the voice of science. Its aim is to assist the thinking and working of the wind power sector, enlighten public decision-making and provide markers and inspiration to adapt practices for better reconciliation between the development of renewable energies and biodiversity preservation.

# Sommaire

## CONTEXT ..... p. 4

### The role of wind power in the mitigation of climate change ..... p. 5

- Climate change impacts all ecosystems and human societies ..... p. 5
- Wind power, an effective tool in energy transition ..... p. 5
- French energy policy aims at major development of wind power in the next few years ..... p. 7

### The development of wind power must be carried out in compliance with biodiversity preservation objectives ... p. 8

- Biodiversity is undergoing a major crisis due to human activities, converging with the climate crisis ..... p. 8
- Wind turbines are an additional risk factor for biodiversity ..... p. 9

### Solutions exist to limit the impact of wind power on ecosystems ..... p. 15

- French regulations set guidelines for the development of renewable energies with regard to environmental issues ..... p. 15
- Taking biodiversity fully into consideration right from the project planning and design phase will effectively avoid some environmental impacts ..... p. 18
- Reducing impacts in wind power projects ..... p. 19

## PERSPECTIVES & FEEDBACK ON EXPERIENCE ..... p. 22

### Reducing bat mortality risks through curtailment measures for onshore wind turbines ..... p. 23

### Reducing bird strike risks through predictive curtailment measures ..... p. 30

### Automatic detection systems (ADSs) for avifauna ..... p. 37

### Reducing underwater noise during the worksite phase is crucial in offshore wind power projects ..... p. 43

## RESEARCH AVENUES FOR REDUCING FLYING FAUNA MORTALITIES ..... p. 48

## RECOMMENDATIONS ..... p. 50

## BIBLIOGRAPHY ..... p. 52



Iles d'Yeu and Noirmoutier wind farm © Paul Bonfils

# CONTEXT

# THE ROLE OF WIND POWER IN THE MITIGATION OF CLIMATE CHANGE

## CLIMATE CHANGE IMPACTS ALL ECOSYSTEMS AND HUMAN SOCIETIES

In 2024, atmospheric carbon dioxide levels reached a record 427 ppm (parts per million, i.e., 0.0427%), increasing at a rate never seen since the concentration of the gas started to be measured in the 1950s. This situation has multiple and interdependent consequences. The planet has undergone a mean increase in temperature of more than 1.1°C since the pre-industrial era, already causing extreme climate phenomena and modifications to numerous natural habitats which affect food security, access to water, and human health, and increase the extinction risk of species and the loss of services provided by ecosystems<sup>1</sup>. To limit these impacts, drastic and rapid reductions in greenhouse gas emissions are required.

Climate change is principally caused by the increase in greenhouse gas emissions<sup>2</sup>, coming from the combus-

tion of fossil energy sources, deforestation and agricultural practices – responsible not only for the emission of carbon dioxide (CO<sub>2</sub>), but also other high-potential greenhouse-effect gases, such as methane or nitrous oxide. The global emissions of the various sectors are expressed as CO<sub>2</sub> equivalent tonnes, which also include the other molecules.

Moreover, the importance of energy sobriety does not seem to be sufficiently taken into consideration, even though it is a simple and effective means of reducing greenhouse gas emissions and impacts on human societies. Energy transition toward renewable energies and sober practices therefore needs to be considered as a priority in public policies on investment and support for innovation.

## WIND POWER, AN EFFECTIVE TOOL IN ENERGY TRANSITION

Worldwide, the production of electricity is the sector that emits the most CO<sub>2</sub>, representing 42% of total emissions<sup>3</sup>, due to the combustion of coal, fuel oil or gas in the thermal power stations used in most countries of the world. Energy transition is therefore a major tool for mitigating climate change by promoting the deployment of renewable production capacities, in particular solar or wind technologies. These energy sources have a largely positive climate footprint, considerably superior to that of fossil energy sources. In addition, renewable energies are of major interest in terms of economics, geopolitics and public

health; their development enables widespread energy sources to be exploited locally and therefore limits the trade gap, improves the energy sovereignty of countries without hydrocarbon reserves, and reduces the pollution stemming from their extraction, transformation, transport and combustion. In France, electricity production is largely decarbonised thanks to nuclear power and the renewable capacities already being exploited, although the primary energy mix still includes approximately 40% of fossil energy sources (principally oil and gas)<sup>4</sup>. Energy transition therefore consists above all in reducing energy consumption

1. Ecosystem services are defined as the advantages that ecosystems provide to humans, in various forms such as the production of oxygen in the air, natural water purification, pollinizing crops, natural carbon sequestration or the recycling of nutrients.

2. IPCC, 2023.  
3. AIE, 2022.



by setting up energy sobriety and efficiency policies, and replacing fossil energy sources by low-carbon energies, which amongst other aspects requires investment in electrification.

Wind turbines convert the kinetic energy of the wind into electricity. Current technological advances enable increasingly high yields, with the largest machines set up offshore now reaching power outputs up to 20 MW<sup>5</sup>. These innovations reduce setup costs and open the possibility of exploiting the potential of the wind where smaller turbines were not cost-effective, thus increasing electricity production, especially for offshore wind power where winds are more constant. The carbon footprint of wind turbines is very low, esti-

mated at approximately 14 g<sub>CO2eq</sub>/kWh for an onshore turbine and 16 g<sub>CO2eq</sub>/kWh for an offshore turbine, while for fossil energy sources it reaches 418 g<sub>CO2eq</sub>/kWh for a gas-fired power station, 730 g<sub>CO2eq</sub>/kWh for an oil-fired power station and 1060 g<sub>CO2eq</sub>/kWh for a coal-fired power station<sup>6</sup>. In addition, wind power is increasingly competitive, with a mean production cost that fell by 39% between 2012 and 2022 in France before stabilising at around 60 €/MWh<sup>7</sup>.

For offshore wind power, while the cost is higher than onshore due to additional technical constraints, the production potential is considerable thanks to more constant wind and larger machines capable of exploiting wind resources better.



Lapwings and Golden Plovers © Alexandre Bertheau

4. SDES, 2025.

5. The Chinese constructor Mingyang Smart Energy's MySE 18.X-20MW wind turbine, set up in August 2024 in the province of Hainan, produces the equivalent of the consumption of 20 600 French households with a load factor of 50%.

6. Empreinte database, Ademe.

7. Ademe, 2024.

## FRENCH ENERGY POLICY AIMS AT MAJOR DEVELOPMENT OF WIND POWER IN THE NEXT FEW YEARS

In its combat against climate change, the European Union has fixed the objective of a 55% reduction in greenhouse gas emissions by 2030 compared to the 1990 level. In this framework, France has set up tools for directing its energy transition policy; the National Low-carbon Strategy (SNBC) and the Pluriannual Energy Programme (PPE). While the aim of the SNBC is to define the roadmap for long-term mitigation in all sectors, the PPE precisely describes the orientations of the energy policy in the next ten years. This issue is primordial, because the production and consumption of energy account for approximately 70% of greenhouse gas emissions in France<sup>8</sup>. The PPE therefore steers the decarbonation strategy for the French energy mix, based on reduced consumption, electrification (transport, heating, manufacturing) and the development of low-carbon energies to respond to this future rise in demand for electricity. It plans for a level of decarbonised electricity production of at least 650 TWh by 2035, provided principally by renewable supply systems, i.e., an increase in 42% compared to the production of decarbonised electricity in 2023. This involves maintaining a deployment rate of approximately 1.3 GW/year for onshore wind power and targeting 15 GW of power generation set up by 2035 for offshore wind power (compared to 1.4 GW currently in service and 1.5 GW under construction). For offshore wind power, deployment occurs by means of calls for bids in zones identified by the State in concertation with local stakeholders and submitted for public consultation in the framework of maritime planning for each coastline. In order to ensure achievement by 2035, the 2026-2035 PPE notably provides for attributing some 8 to 10 additional GW by the end of 2026 with the launching of a high-capacity call for bids. By 2030, the State intends to launch several calls for bids for equivalent power levels targeting an objective of at least 26 GW in service by 2040 and at least 45 GW in 2050.



© Pixabay

8. Citepa, CNUCC inventory 2023.

# THE DEVELOPMENT OF WIND POWER MUST BE CARRIED OUT IN COMPLIANCE WITH BIODIVERSITY PRESERVATION OBJECTIVES



## BIODIVERSITY IS UNDERGOING A MAJOR CRISIS DUE TO HUMAN ACTIVITIES, CONVERGING WITH THE CLIMATE CRISIS



Biodiversity defines “the variability of living organisms of all origins, including terrestrial, marine and other aquatic ecosystems, together with the ecological complexes which they are part of. It includes diversity within species and between species, and the diversity of ecosystems together with the interactions between living organisms”<sup>9</sup>. Biodiversity ensures the survival of all living beings, including human societies, by providing essential goods and services: water, food, medicines, energy and fuels, pollination, soil fertility, climate regulation, etc. In Europe, 72% of non-financial companies directly depend on ecosystem services according to the European Central Bank. Worldwide, more than half of Gross Domestic Product (GDP) depends on services provided by nature and biodiversity<sup>10</sup>.

Nevertheless, human activities are the main reasons for the decline in biodiversity, with ecosystems being fragilized, transformed or even destroyed at a rate unprecedented in the history of humanity according to the Intergovernmental Platform on Biodiversity and

Ecosystem Services (IPBES). The five main causes of the erosion of biodiversity are the destruction and fragmentation of natural habitats (via the development of agriculture, urbanisation and infrastructure), direct exploitation of natural resources (overexploitation, overfishing<sup>11</sup>, deforestation ...), climate change, pollution and the propagation of invasive alien species. The situation observed in France is alarming: 80% of natural habitats of community interest have poor ecological status, 16% of species are threatened or already extinct<sup>12</sup>, and populations of insects, birds and other wild animals have collapsed.

Climate disorder, caused and accelerated by human activities, is one of the five causes of the collapse in biodiversity (IPBES, 2019) and its role is probably set to accentuate due to its increasing pace and the intensification of its consequences. Moreover, habitat degradation actually exacerbates this climate imbalance because numerous ecosystems play the role of carbon sinks (oceans, forests, wetlands ...). Indeed, terrestrial (notably soils) and marine ecosystems currently absorb approximately 50% of CO<sub>2</sub> emissions, but this figure is falling due to the increase in the temperature of oceans and the degradation of the conservation status of natural areas. The biodiversity and climate crises are thus intimately linked, with each leading to repercussions on the other: combating climate change to the detriment of biodiversity would therefore be counterproductive.



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9. French Code of the Environment, Art. L.110-1.  
10. World Economic Forum, 2020. *The Future of Nature and Business*, New Nature Economic Report II.

11. For marine ecosystems, direct exploitation of living organisms is the factor that has the greatest relative incidence, followed by the change in the utilisation of land and sea (IPBES, 2019).  
12. SDES, Bilan environnemental 2024.

## WIND TURBINES ARE AN ADDITIONAL RISK FACTOR FOR BIODIVERSITY

The production of wind power impacts biodiversity. These effects depend on the location and nature of the sites where it is set up, their importance for species sometimes with a poor conservation status, the types of projects together with the ways they are designed, the organisation of the worksites and the operation of wind farms. Wind turbines can generate various impacts: i) effects in the air column and on the ground (area covered by the machines and connected activities), which change the living conditions of wild fauna and flora and are likely to cause the destruction, degradation or alteration of habitats, ii) a loss of habitat by certain species through aversion, iii) a “barrier effect” (obstacle to the movements of flying fauna), iv) direct mortalities principally of birds and bats, together with v) disturbances of fauna due to modification of the electrical field linked to the presence of junction cables.

### EFFECTS OF ONSHORE WIND POWER

#### IMPACTS DURING THE WORKS PHASE

In France, the first wind turbines were set up in the late 1990s, mostly in the south of France, in natural areas such as garrigues and maquis. With the increase in the size of the blades, enabling less powerful winds to be exploited, during the 2000s wind farms were set up in a broader range of habitats, particularly in the agricultural plains where approximately 80% of wind turbines are now sited. In addition, the increase in the height of the machines also makes it technically possible to set them up in forested areas and capture the wind above the canopy.

The area on the ground covered by wind turbines is small, between 15 and 30 m<sup>2</sup>, but they require 300 to 700 m<sup>2</sup> of earthworks to pour the concrete foundations and sometimes land clearing, together with storage areas for excavated earth close to each foundation. The construction of a wind turbine also involves the impact of a 1000 to 1500 m<sup>2</sup> platform for the worksite machinery and crane. Additional surface areas will be occupied throughout the operating phase by the substation, parking area for maintenance and routes

created or widened to enable access to the wind farm as from the start of works. Finally, wind turbines are connected to each other and the substation by a buried cable network, which may either be incorporated into the access routes or connect the machines by the shortest path, across open ground, creating new linear site coverage during the works phase. The impacts resulting from these pressures on habitats largely depend on the local ecological context and the technical characteristics of the project.

#### IMPACTS DURING THE OPERATING PHASE

Aside from their impact on habitats during the construction and dismantling phases, the most documented and well-known direct effects of onshore wind farms occur during the operating phase for flying fauna, in particular birds and bats. Other taxa can be affected, such as certain populations of land mammals.

#### IMPACTS ON AVIFAUNA

Collisions of birds with the blades (strikes) are the most frequently mentioned impact regarding wind power. Wind farms can also cause disturbance and behaviour modification among certain species. Indeed, in addition to potential alterations to or destruction of habitats during the works phase, setting up wind turbines can alter the abundance or distribution of certain species with, in numerous cases, an observed loss of habitat<sup>13</sup>. In addition, wind farms can create a “barrier effect” for numerous birds on migration, whether seasonal or even daily, exposing them to strike risk or forcing them to go round the sectors concerned and thus increasing the energy expenditure associated with their flight. Behind wind farms, which alter air flows, a wake effect can also disturb birds’ flight. There is therefore a loss or, at least, degradation of the access conditions to functional breeding or hunting habitats for sometimes protected species. For birds that do not detect wind turbines or the risk linked to the rotation of the blades, direct mortality can be due to a strike or possibly, among small passerines, a barotrauma (a potentially fatal internal lesion caused by sudden variations in atmospheric pressure due to the movements of the wind turbines’ blades).

13. For example, Riols & Loyrette (2015), Ilty & Duriez (2018) or Marques *et al.* (2017).



Pallid Harrier © Alexandre Bertheau

The species most frequently found at the foot of wind turbines include, for example, the Common Firecrest, Common Swift, Common Kestrel, Black-headed Gull, Eurasian Skylark and Common Buzzard<sup>14</sup>. Diurnal raptors, all fully protected in France, are particularly at risk due to their flight behaviours and the poor conservation status of some populations; they need to be prioritised in project studies and impact mitigation measures.

Bird mortality depends on numerous factors, notably the type of habitat and its utilisation by avifauna (nesting, feeding, roosting, flight path, etc.), the proximity of biodiversity hotspots (protected areas, hedgerows, woodlands, wetlands, etc.) and the technical characteristics of the machines – in particular the surface area swept by the rotor, the height of the bottom tip of the blades and the rotation speed.

### THE VULNEO PROJECT,

coordinated by the Mediterranean Institute of Biodiversity and Marine and Continental Ecology (IMBE) and finalised in January 2025, consists in assessing the sensitivity and vulnerability of avifauna to onshore wind turbines in Metropolitan France, in the context of selecting future sites for setting up onshore wind farms with lower environmental impact. To do so, 142 bird species were studied by combining indices on extinction risk (demography, conservation status, relative size of French populations at European scale) and strike risk based on their flight behaviour (notably the time spent at the height of the zone swept by the wind turbine rotor, estimated from GPS remote sensing data or morphological criteria). The birds' vulnerability is calculated by cross matching their sensitivity to onshore wind power with the density of turbines per grid cell. The results of the analysis show that the species most sensitive to wind power are large raptors such as, above all, vultures (for some of which wind turbines are among the main causes of mortality<sup>15</sup>), the Golden Eagle, Common Crane or Red Kite.

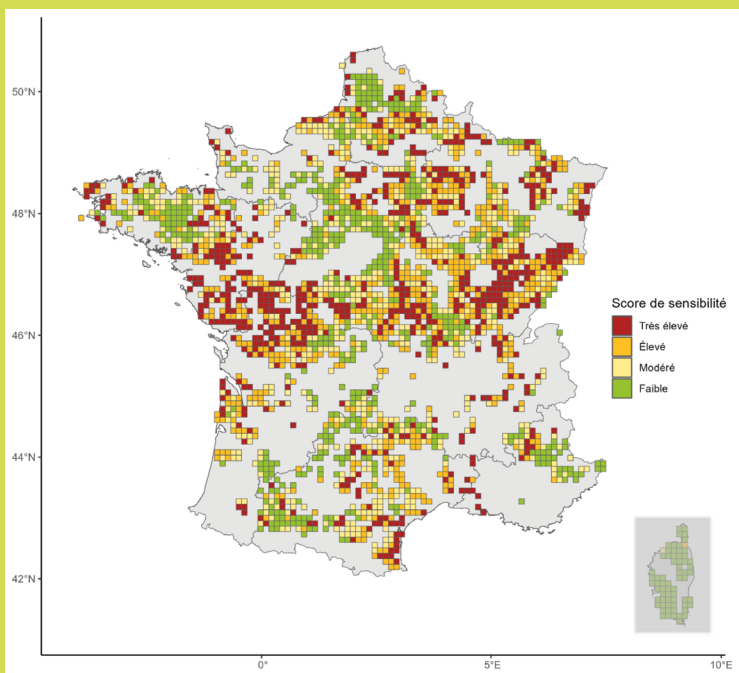
Other highly sensitive species principally include large, high-flying birds such as big gulls, storks, swans and geese.

14. Marx, 2017.

15. National Action Plan for the Griffon Vulture.



By cross-matching the sensitivity of species, their range and the geographical distribution of French wind farms, the researchers defined a relative vulnerability score, topped by species of the agricultural plains and open habitats, which are highly exposed to wind farms (Eurasian Stone-Curlew, Little Bustard, small falcons, gulls, Northern Lapwing, Montagu's Harrier, Hen Harrier, Common Buzzard, etc.). This indicator enables a hierarchy to be established that is more representative of species in function of their real risk of wind turbine mortality.



*Spatial distribution of the global wind power sensitivity score of bird communities present in the grid cells with potential for wind power production (the grey areas correspond to sectors without wind power potential). The values for Corsica are not representative due to insufficient sampling of the avifauna.*

Source : VULNEO project report.

Mapping the sensitivity scores for all the species studied enables the highest-issue sectors to be identified. It can be clearly seen that the distribution of sensitivity levels in Metropolitan France is not homogenous. Obviously, these maps cannot replace local and case-by-case studies about projects. The VULNEO project researchers then calculated the potential wind power production for all the grid cells to compare it with the objectives of the DPE, providing an estimation that those objectives could be achieved by setting up wind farms only in the grid cells where bird communities with low global sensitivity scores are present. This assessment, while only indicative, highlights the potential for avoiding avifauna mortality risks by means of planning enlightened by scientific data.

## IMPACTS ON BATS

Like avifauna, bats suffer direct impacts from wind turbines through strikes and barotraumas<sup>16</sup>, and indirect impacts through modification of habitat conditions. Yet bat species are all strictly protected in Metropolitan France, with a number of them showing worrying population trends and being covered by national action plans since 1999.

The modification of habitats caused by wind power projects can have very different impacts on bat species in function of the habitats modified. The loss of a plot of cereal cropland will have a negligible impact compared to that of a broadleaf or mixed woodland, hedged meadow or wetland. In woodland, setting up a wind farm has very variable impacts on bats: land clearance can destroy roosting trees while opening up clearings and forest tracks creates zones potentially favourable to the movements of bats and their hunting activity, which nevertheless exposes them to a higher mortality risk if the turbines are situated nearby. European recommendations (Eurobats agreement) and research work<sup>17</sup> both indicate that setting up wind turbines away from favourable habitats is primordial for limiting their impacts. Finally, it can be observed that wind farms tend to generate effects on bats' behaviour, causing both an attraction to the machines and an aversion to the wind farm, which seem partly linked to wake effects<sup>18</sup>. These behavioural disturbances, which are starting to be scientifically characterised, depend on the species, period of the year and weather conditions<sup>19</sup>.

Bat mortality is globally more frequent than bird mortality<sup>20</sup>, but not all species have the same sensitivity. In North America and central Europe, mean strike rates are estimated at between 12 and 14 bats killed per wind turbine per year<sup>21,22</sup>. In Europe, while the populations of low strike-risk species seem to be stable or increasing<sup>23</sup>, after a collapse during the 20<sup>th</sup> century due to the changes in agricultural practices and mass use of synthetic pesticides, a decline is still being observed for high strike-risk species. For



Grey Long-eared Bat © Aurélien Audevard

example, the Common Noctule population collapsed by 53% between 2006 and 2023 in France<sup>24</sup>, a trend which is also observed in central Europe<sup>25</sup>, despite its national and international protected status. Its feeding behaviour is a risk factor because species which hunt high in the sky (such as noctules and bats of the Vespertilionidae family) are more vulnerable than those which feed at low altitude<sup>26</sup>. In addition, migratory species (such as noctules and certain pipistrelles) are also very exposed to strike risk - a peak in mortality is recorded between August and September, the period of their autumn migration. Moreover, bats seem to make little use of echolocation to find their way on migration, relying rather on eyesight, which they use to fly at altitudes where they do not expect to encounter obstacles. They are capable of detecting the towers of wind turbines<sup>27</sup>, but seem to poorly perceive the moving blades.

These mortality risks can be accentuated by an attraction phenomenon sometimes observed around wind turbines. Certain species, notably tree-dwelling ones such as Nathusius' Pipistrelle (the species the second

16. Bats' lungs are particularly large and flexible, with a very fine and fragile alveolar membrane, poorly resistant to abrupt variations in atmospheric pressure.

17. Barré *et al.*, 2023.

18. Leroux *et al.*, 2024.

19. Roemer *et al.*, 2017.

20. Marx, 2017.

21. American Wind and Wildlife Institute, 2020.

22. Voigt *et al.*, 2022.

23. Van der Meij *et al.*, 2015.

24. Vigie-Chiro, National Museum of Natural History, 2024.

25. Printz *et al.*, 2021.

26. Roemer *et al.*, 2017.

27. No bat mortality has been recorded for a stopped wind turbine, according to Gaultier, Marx et Roux, 2019.

most frequently found at the foot of wind turbines in France and Europe), tend to be attracted by the machines. Wind turbines are large structures in the landscape, around which these social animals tend to group, adopting the same behaviours as with large trees, to roost or breed (this swarming phenomenon occurs during autumn migration) and to feed on insects – possibly attracted by the warning lights and the heat emitted by the turbines<sup>28</sup>. The opening up of woodland habitats linked to the construction of certain wind farms also plays a role in this attraction phenomenon for individuals as they move around.

## EFFECTS OF OFFSHORE WIND POWER

Concerning wind power at sea – offshore wind power – certain impacts are similar to onshore wind power concerning risks for flying fauna, although they are significantly less well documented and also affect taxa living in the marine environment. Nonetheless, numerous aspects specific to offshore wind power make it worth detailing below the possible risks for the various compartments concerned<sup>29</sup>.

### IMPACTS DURING THE WORKS PHASE

Setting up wind farms and connecting them to the electricity network require sometimes heavy works on the seabed, such as driving or boring piles or anchorages, together with trenching for cables. These works, whose scale and nature depend on the technologies used, lead to the destruction of habitats, re-suspension of materials and disturbance of the seabed, together with noise and vibrations. Cable landing points cause potentially significant impacts to beaches and dune areas. In addition, the circulation of worksite vessels increases the frequentation of the site, which can cause a rise in noise levels, a risk of collision with marine mammals, disturbance of birds resting on the water or feeding (auks, shearwaters, sea ducks...) and possibly pollution. The effects on marine ecosystems of dismantling wind farms are similar to those of the works phase, although there is little literature on the subject due to the current lack of feedback on experience.

28. OPRECh Programme, 2022.  
29. UICN, 2014 and UICN, 2023.

## EFFECTS DURING THE OPERATING PHASE

### IMPACTS ON FLYING FAUNA

During the operation of the wind farm, effects similar to onshore wind power are to be expected, with a risk of strikes with flying fauna. Marine habitats are used by numerous migratory species, which fly at variable altitudes and times in function of the species, period of the year and meteorological conditions. These migratory animals – birds and bats – may not only fly along coastal areas but also cross seas and oceans, which also makes them vulnerable to wind farms positioned far from the coast. Bats have even been spotted more than fifteen kilometres offshore, during daily movements outside the migration period<sup>30</sup>. In addition, numerous seabirds can be strike victims, notably in poor meteorological conditions. These birds can also suffer a loss of habitats<sup>31</sup>, notably in the case of pelagic diving birds. Finally, it should be noted that the foundations or floats may be used by certain birds as resting places or feeding sites (due to the “reef effect” causing a local rise in biomass), increasing the strike risk for the wind turbines.

30. Chabrolle comm. pers.  
31. BirdMoue project report, 2025.



## IMPACTS ON UNDERWATER FAUNA

During the operation of offshore wind farms, the vibrations due to the rotation of the turbines emit significantly lower sound levels than in the construction phase, lower than those of maritime transport or the ambient noise in the marine environment, therefore without notable incidence on living organisms<sup>32</sup>. Nevertheless, maintenance operations on the facilities require the movement of vessels, which can result in a risk of fauna disturbance, or even strikes with marine mammals. It should be noted that certain wind farms also offer industrial tourism activities with, in some cases, numerous daily public boat tours, leading to additional disturbance of marine fauna.

Operating the wind farm may have other potential impacts. Firstly, there are possible effects linked to underwater cables with the creation of electromagnetic fields, to which particularly rays, sharks and amphihaline fish (migrating between marine and freshwater habitats) are sensitive, and whose behaviours and movements can be affected close to electrical connections<sup>33</sup>. An increase in temperature

can also be noted around the cable, although its consequences for the benthos (the set of organisms living in or on seabed substrates) seem to be fairly marginal<sup>34</sup>. A biofouling phenomenon often occurs on immersed structures, notably for floating wind power (floats, cables), leading to the depositing of organic matter on the seabed, causing a potential modification of the habitat. Two types of protection are used to limit the corrosion of immersed metallic structures. Galvanic anodes, much used in the marine environment, typically on vessels' hulls, diffuse metal ions in the water while impressed current cathodic protection (ICCP) systems generate chlorinated derivatives, substances toxic to marine organisms<sup>35</sup>. Finally, the rotation of the turbines generates a wake effect as far as more than 70 km downwind from wind farms, which can lead to a 40% reduction in wind speed at altitude<sup>36</sup> and an upwelling of water masses between the wind farm and the coast. This upwelling phenomenon, bringing up water loaded with sediment nutrients, generally results in proliferations of (sometimes toxic)<sup>37</sup> phytoplankton which can have a domino effect on the distribution of all the links in associated food chains<sup>38</sup>.



Striped Dolphin © Paul Bonfils

32. IUCN French Committee, 2014.  
33. Dernouny, 2022.  
34. IFREMER, 2019.  
35. PolluEcume project report, 2024.

36. Liu *et al.*, 2023.  
37. Grosdemange comm. pers.  
38. CNRS, 2021.

# SOLUTIONS EXIST TO LIMIT THE IMPACT OF WIND POWER ON ECOSYSTEMS

## FRENCH REGULATIONS SET GUIDELINES FOR THE DEVELOPMENT OF RENEWABLE ENERGIES WITH REGARD TO ENVIRONMENTAL ISSUES

### AT NATIONAL SCALE

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted at the Earth Summit in Rio de Janeiro, recognising the existence and impact of climate change, one of the key documents on sustainable development alongside the Convention on Biological Diversity. The Kunming-Montreal Global Biodiversity Framework was ratified at the 15<sup>th</sup> Conference of Parties (COP) to the Convention on Biological Diversity in Montreal in 2022. It commits signatory states, including France, to stop and reverse the biodiversity erosion trend by 2030. In parallel, the European Union provides a framework for the protection of ecosystems with tools such as the “Habitats” and “Birds” Directives, creating the Natura 2000 network, the Nature Restoration Regulation and Marine Strategy Framework Directive (MSFD). Regarding energy transition, the Renewable Energy Directive (RED) fixes objectives for the production of renewable energies and introduces mechanisms to simplify administrative procedures such as defining acceleration areas for renewable energy production (RAAs).

In order to honour its international and European commitments, the French government drew up its National Biodiversity Strategy (SNB) for 2030, including measures for achieving the targets of the Kunming-Montreal worldwide framework. One of the principal thematic areas includes assisting priority sectors to reduce their environmental impacts, notably strengthening the consideration of biodiversity pro-

tection issues in energy infrastructure<sup>39</sup>. This measure is divided into several actions: making it forbidden to put RAAs in certain protected areas (national parks, nature reserves, terrestrial Natura 2000 sites for bats, strong protection areas at sea), funding research and development projects to improve impact reduction techniques, and enhancing knowledge on the link between renewable energies and biodiversity by means of a specific offshore wind power observatory and an onshore renewable energies observatory.

In response to the objective of deploying renewable energies in France, several territorial planning initiatives have been devised such as the mapping of zones favourable for the development of onshore wind power, requested from regional prefects in 2021, or the law on accelerating the production of renewable energies, referred to as the APER Law, promulgated March 10<sup>th</sup>, 2023. This law is based around four thematic areas: planning the deployment of renewable energies in local areas with local elected officials, simplifying project authorisation procedures, using already artificialized areas and sharing the value of projects with the local areas in which they are situated. It tackles biodiversity questions by incorporating several provisions. Firstly, it formalises the creation of the Observatory of Renewable Energies and Biodiversity, aimed at inventorying knowledge and the impacts of renewable energies on biodiversity. It also completes SNB 2030 by restating that priority areas for the development of offshore wind power need to take biodiversity conservation objectives into account, particularly in marine protected areas<sup>40</sup>.

39. National Biodiversity Strategy 2030, Axis 1.2, Measure 15.

40. It should be borne in mind that marine protected areas are incompatible with the deployment of industrial activities including the setting up and connection of renewable energies according to the IUCN French Committee and the worldwide IUCN.

Finally, in the framework of the sharing of value with local areas, it stipulates that the applicants chosen after bidding procedures or calls for offshore wind power projects are committed to financing biodiversity protection or safeguarding projects. This provides the framework for creating the biodiversity funds linked to offshore wind power bidding procedures, managed by the water agencies.

## AT PROJECT SCALE

Renewable energy projects, like other industrial and planning activities, are bound by regulatory provisions to ensure a minimum impact on biodiversity. In particular, wind turbines are subject to the regulations for facilities classified for the protection of the environment (ICPE)<sup>41</sup>. Wind turbines whose towers are higher than 50 m and wind farms whose total power setup is greater than 20 MW and where the tower of at least one turbine is higher than 12 m are subject to an environmental authorisation procedure. The application for authorisation must include an impact study, carried out under the responsibility of the project leader, which assesses, amongst other things, the potential or proven effects of the wind power project on the environment and analyses and justifies the choices made with regard to identified issues.

The aim of this impact study is to protect the environment by establishing the most exhaustive possible initial status assessment, based on robust studies and proposing measures to adapt the project according to an iterative principle, mitigating its impacts notably to comply with the “zero net loss of biodiversity” principle. The impact study therefore assists the design of the project by taking issues and

sensitive aspects into consideration and also informs the public about the reasons for the project, initiatives undertaken and expected effects. Finally, it also aims to enlighten public authorities on decision-making with regard to the environmental issues of the local area concerned.

The content of this impact study is proportioned in function of the environmental sensitivity of the area involved and the nature of the intended works. It endeavours to analyse environmental issues at various scales: in the potential setup zone, immediate study area (including a buffer zone of several hundred metres), close study area (corresponding to the principal zone of possible functional effects on populations of flying fauna species) and far study area (which covers all potential impacts and includes the area of analysis of the cumulated impacts of the project with other wind power, local development or infrastructure projects). The impact study contains an analysis of the initial environmental status to identify and prioritise all the issues of the habitats likely to be affected by the project so as to define the environmental specifications with which the project needs to comply. Thereafter, the core of the impact study is the assessment of the project’s effects on the environment. The “raw” impacts of the project are assessed without avoidance and reduction measures, then the “residual impacts” are estimated taking these measures into account. The contracting authority is committed to these measures, which need to be feasible, precisely described, calculated and covered by monitoring measures. If, notwithstanding the impact reduction measures, the destruction of one or more habitats of protected animal or plant species cannot be avoided, the creation of a substitute habitat can then be envisaged. The new habitat must comply with the principles of a compensatory measure, be away from the risk area and be covered by rigorous scientific monitoring. The compensatory measures need to be on a sufficient scale, implemented throughout the duration of the impacts as close as possible to the damaged site for the same types of ecosystems and species as those impacted by the project. They generally take the form of restoring degraded natural sites, creating new habitats and ecological management of habitats.



Red Kite © Alexandre Bertheau

41. Law 2010-788 (Grenelle II).

This process of integrating environmental issues is central to the planning, design and carrying out of projects. All the environmental measures are defined following a logical sequence, aiming firstly to avoid biodiversity impacts then, if necessary, to reduce those that could not be avoided and finally to compensate if avoidance and reduction prove insufficient. The aim of this “avoid-reduce-compensate” (ARC) sequence is zero

net loss or even a gain in biodiversity in the execution of local development projects. If its impacts cannot be avoided, reduced or compensated, a project cannot be authorised without being modified<sup>42</sup>. Monitoring of ARC measures is generally carried out after setting up renewable energy projects, it is obligatory in the case of wind power projects.

### THE AVOID-REDUCE-COMPENSATE (ARC) SEQUENCE,

introduced into French law in 1976, provides a standardised framework for assessing and reducing the impact of local development plans and projects, with the aim of causing no net loss of biodiversity, or even a gain. This method provided a methodological basis common to all types of projects by integrating environmental issues into their design, enabling contracting authorities to make choices with regard to them. Its principle is to establish a hierarchy between natural habitat protection measures, starting by avoiding any negative impacts of the project, then by reducing the extent of impacts that could not be avoided and finally by compensating the residual impacts by providing an ecological equivalent or improvement. These measures can be completed by assistance and monitoring measures to ensure and assess their success. The monitoring protocols are defined as soon as the environmental authorisation is granted and may lead to an adaptation of the ARC measures if significant differences are observed between the expected and real impacts of the project.

Avoidance measures are the only ones capable of eliminating certain impacts of the project on biodiversity and therefore need to be given priority consideration before reduction and compensation measures. Avoidance consists in comparing several setup scenarios so as to choose the option ensuring the least impact on biodiversity. If no scenario seems fully satisfactory with regard to residual issues, application of the avoidance process may result in a project being abandoned. Some technical or timing adaptations during the work-site or operating phase are sometimes considered as avoidance, but they cannot generally demonstrate the strict absence of impacts and should therefore be qualified as reduction. Indeed, they aim to reduce the duration, intensity and extent of negative impacts that could not be avoided.

42. According to Article L. 163-1 of the French Environmental Code.



Finally, compensation measures are to set up to provide at least an ecological equivalent in the event of residual impacts, i.e., those that could neither be avoided nor reduced. The objective of compensation is to ensure that there is no net loss of any impacted biodiversity element, or even a net gain in biodiversity. These last-resort measures are subject to an obligation of result, need to be long-lasting, effective when the impacts occur and therefore anticipated, and to be set up close to the project so as to ensure their benefits for the affected site or species.

## TAKING BIODIVERSITY FULLY INTO CONSIDERATION RIGHT FROM THE PROJECT PLANNING AND DESIGN PHASE WILL EFFECTIVELY AVOID SOME ENVIRONMENTAL IMPACTS



Cross-validated mapping of issues right from the planning of projects is fundamental to avoid setting up wind power infrastructures in sensitive areas for biodiversity. Projects cannot be planned purely on the basis of a land tenure opportunity or favourable wind conditions. The planning of wind power needs to include the regulations and technical constraints such as wind resources, topography, the nature of soils or seabeds, environmental and social considerations, cumulated effects, accessibility and connection to the network. The identification of environmental measures aimed at apprising and minimising negative effects on biodiversity and ecosystem services is a primordial consideration throughout the project planning and design phase.

Thorough knowledge of the ecological issues even before the planning phase is essential for assessing the impact risks and identifying the appropriate measures. The most effective are generally incorporated right from the planning and design phase, while changes to the positioning of infrastructures and operational planning still remain possible. This iterative process needs to be repeated until the residual impacts are manageable, limiting the need for compensatory measures, which are often non-existent, costly and

sometimes difficult to implement, especially in the marine environment or tight land-tenure contexts.

The zones to avoid when planning projects include protected areas and strong protection zones, the habitats of threatened or vulnerable species, areas with a high density of flying fauna (for example, at sea, along favourable depth contours), sectors concentrating movements of fauna such as major migration corridors and stopover sites, certain hilly or mountainous areas, “bottlenecks” (valleys, straits, barrier beaches, headlands and capes) and certain linear elements (rivers and streams or forest edges, particularly for bats). Appropriate avoidance zones around these sensitive sectors should be set up in order to minimise the risk of disturbance and wind turbine strikes for vulnerable species. To this end, researchers recommend “buffer” zones between favourable habitats and the sites of renewable energy facilities, whether for bats<sup>43</sup>, birds<sup>44</sup> or even certain mammals<sup>45</sup>.

43. Eurobats recommendations.

44. For example, an avoidance distance of 2 km is recommended by De Pracontal *et al.*, 2020 around sites used by the Little Bustard, which is consistent with the recommendations of Bretagnolle *et al.*, 2025.

45. For example, Portuguese regulations exclude wind power and connection infrastructures within a radius of 2 km around known Wolf breeding sites, according to a study by Ferrão da Costa *et al.*, 2018.

## REDUCING IMPACTS IN WIND POWER PROJECTS

For the planning and design of a wind power project, if avoidance measures cannot eliminate all the environmental impacts that may be generated, reduction is the second step in the sequence. Its aim is to obtain the lowest possible residual impacts, causing no notable loss of biodiversity or ecosystem services. Reduction measures are set up on the project site, or in its immediate vicinity. They concern the worksite phases (construction and dismantling), which can prove detrimental to habitats and the maintenance of their biological functionalities, together with the operating phases of the wind farm and its infrastructures.

Reduction measures can be categorised in three different types: geographical, technical and timing reduction, each applicable to the construction, operating or dismantling phases. Geographical reduction consists in limiting the spatial extent of the impacts linked to the project. Technical reduction aims to limit the intensity of the impacts linked to the project. Finally, timing reduction involves adapting the periods and hours of construction and dismantling works, together with the periods and hours of operation, activity and maintenance during the operating phase of wind farm.

Reduction and avoidance measures, sometimes quite similar concerning their application, are frequently confused in impact study documents. The main difference lies in their effect: while an avoidance measure eliminates a potential impact of the project on the environment, a reduction measure cannot guarantee zero impact, and its efficacy depends on several factors such as the equipment used or the meteorological conditions. Typically, one of the first ways to mitigate impacts is optimising the placing of the wind turbines, referred to as “micro-siting”. It consists in siting infrastructure (wind turbines, access routes, connection pathways, technical servicing posts) away from the most sensitive areas for biodiversity, and adapting the layout of the wind farm to minimise obstacles to species’ movements. This micro-siting can therefore be considered as an avoidance measure if it targets certain specific habitats that would otherwise be destroyed but remains a reduction measure if it involves only strike risks. A reduction measure is always associated with a defined impact - for example, a particular layout of wind turbines may reduce their impact but not totally avoid it.



© Paul Bonfils

The national reference base to assist the definition of ARC measures categorises reduction measures as follows, specified here in the context of wind power projects:

TYPE OF MEASURE	PROJECT PHASE	REDUCTION MEASURE
GEOGRAPHICAL REDUCTION	DESIGN	<ul style="list-style-type: none"> <li>Optimising the layout of the turbines and ancillary site coverage (micro-siting).</li> </ul>
	WORKS	<ul style="list-style-type: none"> <li>Protecting sensitive sectors on the project site (flora, habitats).</li> <li>Adapting access routes to limit disturbance to wildlife and destruction of habitats.</li> </ul>
	OPERATING	<ul style="list-style-type: none"> <li>Adapting access routes (maintenance, visits ...) to limit disturbance to wildlife.</li> </ul>
TECHNICAL REDUCTION	DESIGN	<ul style="list-style-type: none"> <li>Machines' dimensions and operating characteristics (height, ground or water clearance, rotation speed ...).</li> <li>Improving the visibility of the wind turbines for birds (painting of blades, tower ...).</li> </ul>
	WORKS	<ul style="list-style-type: none"> <li>Adapting worksite machinery.</li> <li>Optimising the management of materials on the site (rubble/backfill).</li> <li>Reducing the attractiveness of the site for fauna before the works.</li> <li>Removing and re-siting high-priority species before their destruction by the worksite.</li> <li>Combatting the propagation of invasive alien species.</li> <li>Combatting pollution, rainwater and worksite management.</li> <li>Limiting disturbance factors (noise, lighting at night ...).</li> </ul>
	OPERATING	<ul style="list-style-type: none"> <li>Managing habitats in function of the project site issues.</li> <li>Limiting fauna interference factors (noise, lighting ...).</li> <li>Anti-strike measures (reactive or dynamic curtailment): curtailment<sup>⊕</sup> of turbines or acoustic scarers.</li> </ul>
TIMING REDUCTION	WORKS	<ul style="list-style-type: none"> <li>Adapting the period of the worksite during the year (avoiding the most ecologically sensitive periods) or in cases of specific issues (stoppage of offshore works if cetaceans are present).</li> <li>Adapting works hours (in function of ecological issues).</li> </ul>
	OPERATING	<ul style="list-style-type: none"> <li>Adaptation operating periods and hours: static or predictive curtailment.</li> </ul>



Curtailment consists in deliberately stopping a turbine by adjusting the angle of the blades (feathering), in general to avoid a danger of strikes with flying fauna. This curtailment may be planned, with the wind turbines stopped during a predefined period or in meteorological conditions corresponding to a peak in risks calculated by statistical models, in which case it is called passive, static or predictive curtailment. Alternatively, wind turbines may be stopped as a direct reaction to the occurrence of a danger situation (one or more birds or bats flying toward or close to the turbines detected by radar, video or microphone), which is referred to as dynamic or reactive curtailment.

Many of these measures are systematically deployed in French wind power projects, in particular most of the geographical, technical and timing measures applied during the worksite phase. Nevertheless, other measures are the focus of major research and development work because they aim to reduce impacts that are sometimes considerable or still difficult to assess. This concerns, in particular, underwater noise abatement on offshore wind power worksites, investigating the perception of wind turbines by flying fauna,

predictive curtailment based on statistical models, and dynamic curtailment with the mass deployment of various technological solutions. It is sometimes difficult to see clearly among these diverse methods of reducing the impacts of wind power on biodiversity. Do they really work? Is their deployment justified by performances that match up to the seriousness of the issues? Can they really be considered as effective reduction measures?



The following section presents feedback on experience from both scientific experts and project developers on specific pressures such as noise, bat mortality, bird mortality, etc.

It was necessary to respond to these questions by collecting feedback on experience about various wind power projects, on land and offshore, and investigating the world of research and its numerous publications.

Concrete testimonies from the wind sector provide a better understanding of project developers' initiatives and the results of their experimentation.

The literature sheds scientific light on this feedback, providing certain responses and revealing the gaps in knowledge.



Golden Plovers © Alexandre Bertheau

# PERSPECTIVES & FEEDBACK ON EXPERIENCE



## REDUCING BAT MORTALITY RISKS THROUGH CURTAILMENT MEASURES FOR ONSHORE WIND TURBINES

**The issue of bats is important for French wind farms. Metropolitan France has 34 bat species, all fully protected and covered by a national action plan<sup>46</sup>.**

Their slow reproduction strategy, producing a single offspring per year, combined with high longevity (up to about thirty years), makes bat populations very vulnerable to any increase in mortality<sup>47</sup>. The 2017 national red list of bats indicates that eight species are threatened (vulnerable, endangered, or critically endangered) and eight near-threatened<sup>48</sup>, compared to four and seven respectively in 2009. Bats' situation is therefore more and more worrying, due to various human-caused pressures such as the collapse in the insect populations on which they feed, destruction of their habitats (hunting grounds, roosts, resting places ...) and direct mortalities.

Wind farms are a real threat to bats; they can cause strikes or barotraumas, degradation or modification of habitats, and behavioural disturbances<sup>49</sup>. As well as being located on bats' flight paths or close to hunting grounds, wind turbines can have an attraction effect, thus aggravating the risk of mortality. Several hypotheses have been formulated to explain this phenomenon<sup>50</sup>:

- Confusion of wind turbines with very large trees, and using them as resting places during the day or as nuptial swarming sites;
- The presence of numerous insects (themselves attracted by the height of structures, heat emitted and light of the nacelles), bringing the hunting animals near the rotating blades (studies based on thermal imaging have shown that the concentration of insects is a predictor of bats' activity and therefore mortality);
- On land, the construction of access routes and wind farms creates landscape elements (clearings, woodland edges ...) favourable to bats' movements and hunting;
- A response to wind turbines' warning lights, certain species seeming to be attracted by the light (notably the Soprano Pipistrelle by red lights at night<sup>51</sup>);
- Possibly the emission of sounds by the blades at frequencies comparable to those of large insects; bats have already been observed "pursuing" blades in northeast France<sup>52</sup>.

46. Bats NAP 2016-2025.

47. Barclay & Harder, 2003.

48. IUCN French Committee, 2017.

49. OFB Technical Portal ("Ecodesign of onshore wind farm projects").

50. Guest *et al.*, 2022.

51. Voigt *et al.*, 2018.

52. S. Bellenoue pers. comm. in Dulac, 2008.

There are therefore multiple attraction factors for bats by wind farms, highly dependent on the species considered, habitats present around the wind turbines and meteorological conditions, and they still remain difficult to elucidate.

In northwest Europe, where high concentrations of onshore wind turbines have been set up in countries situated on strategic migration routes for numerous European bat species<sup>53</sup>, mortality monitoring indicates that wind farms kill several hundred thousand bats per year (principally noctules, pipistrelles, vesper bats and serotine bats), with very variable numbers in function of their location. Mortality rates seem to be highly correlated to landscape criteria such as topography and vegetation. For example, the highest mortalities are recorded for the wooded hills of southern Germany or the French Atlantic coast, with a mean of 18 to 20 bats killed per wind turbine per year. In intensive agricultural plains, as in northwest Germany, mortality rates are much lower, with on average 0.4 corpses per wind turbine per year. In more varied agricultural landscapes, mortality rates are higher, especially on uplands and close to wooded areas<sup>54</sup>.



Common Bent-wing Bat © Aurélien Audevard

This understanding of the impact of wind farms, combined with models of population dynamics, enables an extinction risk for several species to be anticipated. In North America, the development of wind power is causing the decline of a migratory species, the Hoary Bat (*Lasiurus cinereus*), and could be responsible for its extinction by 2050<sup>55</sup>. The setting up of reduction measures can mitigate this risk; a minimum wind speed for starting the turbine (cut-in speed) set at 5 m/s can on average reduce

bat mortalities by 62% in certain cases<sup>56</sup>. However, measured efficacy rates vary considerably around this mean and never attain zero mortality, even for cut-in speed thresholds set at high wind speeds. This technique therefore shows variable and never total efficacy, and in no event replaces an avoidance process.

The French regulatory framework obliges wind power projects to carry out an impact study. If, after avoiding the most sensitive areas, residual impacts on bats are anticipated, wind power projects need to include reduction measures; the national technical guidelines recommend regulating turbines in function of the period of the year, wind speed and temperature, or guided by a bat detection system. Post-setup monitoring, characterising the activity of bats at the height of the nacelle and mortality under the wind turbines, needs to be carried out for a minimum of 20 consecutive weeks between mid-May and the end of October with at least, on land, one inspection per week at the foot of each wind turbine, or more in function of project issues, corpse persistence time or mortality data.

53. Hutterer *et al.*, 2005.  
54. Rydell *et al.*, 2010.  
55. Friedenber & Frick, 2021.  
56. Whitby *et al.*, 2021.

In France, only 44% of onshore wind farms have set up one or more regulation measures in favour of bats, apparently variably deployed from one region to another<sup>57</sup>. A passive acoustic study at nacelle height can determine the strike risk<sup>58</sup> for each project site and therefore scale the reduction measures appropriate to the species present. A first approach for limiting mortalities consists in stopping the wind turbines in various ways, which can be categorised into four families:

- “Below production threshold” regulation mode: when the wind speed is lower than the technical production threshold, the blades are feathered to avoid them rotating “in thin air” (which can be a cause of mortality for bats, which fly at low or even very low wind speeds).
- “Preventive” or “conventional” regulation mode: in the absence of detailed knowledge of the issues and bats’ flight conditions at rotor height on the site, this measure, which is used by default, is scaled empirically on the basis of a regulation pattern that has proven effective for surrounding wind farms or on a broader scale. Typically, curtailment is often carried out when the wind is below 6 m/s and the air temperature above 10°C<sup>59</sup>. In principle, it is combined with the previous measure, i.e., the blades are feathered below the starting threshold.
- “Predictive” or “multicriteria” regulation mode: this approach is intended to adapt to local risk conditions because numerous factors other than the wind speed and temperature influence mortality risk<sup>60</sup>. In this case, curtailment is scaled on the basis of a detailed perception of the issues identified on the site and the conditions at which the risk of bats flying at rotor height is the highest, modelled by algorithms<sup>61</sup>. This mode prerequisites continuous monitoring of bat activity over at least one control year. In function of the most influential parameters for characterising the risk on the site studied, a multicriteria curtailment pattern (wind speed and direction, temperature, times, period of the year, precipitation, atmospheric pressure, etc.) is defined case-by-case using modelling tools.
- “Dynamic” regulation mode: this technique consists in stopping the turbines in reaction to the real-time detection of bat activity.

Another approach is the emission of ultrasounds to scare the bats, but this method seems to be relatively ineffective, only appropriate for some species, and can only be used in addition to a curtailment measure.

These regulation measures are increasingly being integrated into wind power projects in the development phase, which is linked to a better understanding of the risks, together with the progression of regulatory protocols and national guidelines. Currently, 72% of impact studies for new projects include a proposed curtailment measure in favour of bats, although regional disparities persist and a still significant proportion of constructed wind farms and ongoing projects do not incorporate any regulation measures, which is unacceptable given scientific knowledge about the impact of wind farms on flying fauna<sup>62</sup>.

57. Programme OPRECh, 2022.  
58. Roemer *et al.*, 2017.  
59. Barré *et al.*, 2023.

60. Thompson *et al.*, 2017.  
61. Barré *et al.*, 2023.  
62. Programme OPRECh, 2022.

A motion calling for greater consideration of issues linked to bats, proposed by several international environmental protection organisations including Bat Conservation International, was duly voted at the 2025 World Conservation Congress (<https://iucncongress2025.org/assembly/motions/motion/044>).

## FEEDBACK ON EXPERIENCE



Landscaping of a Vendée wind farm © wpd

### WIND FARM OPERATING IN VENDÉE

In the Vendée department, the company wpd is developing a project consisting of four 3 to 5 MW wind turbines set up on a surface area of 1.77 ha spread across two municipalities. Authorised in November 2024 and intended to be implemented between 2027 and 2028, this project, situated in the renewables acceleration areas of the Sud Vendée Littoral local authority grouping, is located away from any ecological site – the closest being a ZNIEFF I more than 500 metres from the first wind turbine. The project study zone is mostly exploited for field crops, but also includes wetlands, a wood and hedgerows. Nature surveys revealed issues with birds and bats linked to the woodland and hedgerows, notably old trees of major ecological interest (roosts for bats, development of beetles and saproxylophagous organisms ...). The first measure was to avoid as far as possible setting up wind turbines and access routes in habitats of particular ecological interest, natural grasslands, woodlands, wetlands and hedgerows. All facilities and access routes were designed to conserve all the trees of interest; similarly, preexisting openings in the hedgerows were used to lay the underground cables. Access to the wind turbines took into consideration the reduction of impacts on functional hedgerows, with special attention paid to strictly avoiding any tree of ecological interest. In order to optimise the wind turbine setup, a specific bat survey was implemented to identify bat activity in function of the distance from the nearest hedgerows, and the minimum ground clearance of the rotor was set at 40 metres, in compliance with the guidelines of the Pays de la Loire region. Due to the project's land tenure constraints, the wind turbines were set up between 90 and 250 metres from the hedgerows – contrary to the Eurobats recommendation of a minimum distance of 200 metres<sup>63</sup>. To reduce bat mortality, a “conventional” curtailment plan was set up for the whole period of operation of the wind farm.

63. Rodrigues *et al.*, 2015.

The four wind turbines are stopped all night from 1<sup>st</sup> April to 31<sup>st</sup> October as soon as the following conditions are encountered:

- Between 1<sup>st</sup> April and 30<sup>th</sup> June: temperature above 10°C and wind speed lower than 7.6 m/s at a 110 height of metres..
- Between 1<sup>st</sup> July and 31<sup>st</sup> August: temperature above 11°C and wind speed lower than 7.6 m/s.
- Between 1<sup>st</sup> September and 31<sup>st</sup> October: temperature above 10°C and wind speed lower than 8.9 m/s.

These parameters correspond to the conditions that seem the most favourable to bat activity, identified by means of acoustic data gathered by a measurement tower during the project's initial status studies. The maximum proportion of activity covered by this model, therefore corresponding to the theoretically mortality avoided, is between 77% (in spring) and 95% (in autumn). In practice, the efficacy of this curtailment could be determined during post-setup mortality monitoring which, in compliance with the ministerial protocol in force, will be carried out with 24 inspections between mid-May and the end of October for at least the first three years of operation. This mortality monitoring will be combined with monitoring bat activity at nacelle height, carried out continuously over the whole biological cycle for three consecutive years and correlated with the corresponding meteorological data (wind speed, temperature, precipitation).



Bat recorder © wpd

This regulation measure, which is the standard curtailment set up for all projects developed by the company wpd, will lead to electricity production losses estimated at 7% given current meteorological projections.

## WIND FARM OPERATING IN MARNE

The commune where the wind farm was set up, in the Marne department, is situated in an area with a high density of wind turbines. In January 2017, a first wind farm of five turbines was put into operation, enlarged by twelve additional turbines in May 2022 set up by two companies already established in the region, Engie Green (which operates the first five machines) and Romande Energie. The area is very artificialized, exploited for field crops and therefore of little ecological interest. It includes small residual thickets and a few hedgerows, where the bird and bat issues are concentrated. During project extension surveys between 2016 and 2017 ten bat species were detected, using these habitats as hunting grounds and flight corridors. The project was therefore adapted, maintaining a minimum distance of 200 metres between the wind turbines and the hedgerows and woodland margins, and setting up reduction measures during the worksite phase and throughout the operation of the site. To reduce bat mortality, the operator implemented "conventional" curtailment as from 2022 for all the turbines on the wind farm in function of the following parameters: at night from 15<sup>th</sup> June to 15<sup>th</sup> September each year, when the temperature is above 10°C, the wind turbines only rotate when the wind speed exceeds the threshold of 6 m/s.

A protocol to monitor bats' acoustic activity on the ground and at nacelle height, as well as their mortality, was implemented. Mortality monitoring is performed once a week for six months, i.e., 24 inspections per year carried out in the morning to limit risks of predation of the corpses fallen during the night. Raw bat mortality rates were very low over the first post-setup years, with one corpse found the first year and none the second. Nevertheless, these figures are highly dependent on the persistence of the corpses, an indispensable parameter for estimating the real mortality rate<sup>64</sup> which needs to be assessed for each site set up. In addition, the acoustic monitoring of bat activity should quantify the proportion of activity at nacelle level covered by the curtailment plan, in order to assess its performance.

## EFFICACY OF THE MEASURES



Lesser Horseshoe Bat © Aurélien Audevard

### The efficacy of “curtailment for bats” requires a thorough understanding of activity factors and mortality risk

Let us first take the example of a six-turbine wind farm in the Cantal department fitted with a conventional curtailment system which malfunctioned for 24 days in September 2024. During this period, monitoring of the site revealed a high mortality rate, never previously encountered on this wind farm, with four Common Pipistrelles and one Kuhl's Pipistrelle found at the foot of wind turbines<sup>65</sup>.

There are several approaches for stopping wind turbines to protect bats. Not all benefit from the same feedback on experience and knowledge of their performances remains rather uneven<sup>66</sup>. The efficacy of each measure can only be assessed after implementation, via detailed post-setup monitoring and following a robust, standardised protocol that enables the scaling of the measure to be adjusted if necessary.

■ **“Conventional” curtailment**, defined by a threshold starting speed for the wind turbines and adjusting the orientation of the blades to avoid them rotating freely, is the most commonly implemented approach on farms and several studies have attempted to assess its efficacy. They show that the implementation of a starting threshold can considerably reduce bat mortality on wind farms worldwide. Nevertheless, more research is required to confirm the effectiveness of these regulation measures in various contexts, refine seasonal configurations and better understand their long-term effects on bat populations.

64. Ravache *et al.*, 2024.

65. Ministry for Ecological Transition, Bureau of Analysis of Industrial Risks and Pollution.

66. Quinard *et al.*, 2024.

- **“Multicriteria” curtailment** incorporates finer adjustments corresponding to seasonal, meteorological and behavioural variations in bats’ activity. Several studies have tested, in various contexts, diverse combinations of threshold starting speeds and environmental and phenological parameters to estimate their impact on bat mortality and the loss of energy production. These research projects provide a better understanding of how specific adjustments to curtailment plans can influence the efficacy of mortality reduction, thus offering the possibility to refine the algorithms and activity models so as to optimise multicriteria curtailment measures. The higher the number of criteria, the finer the measure and the lower the likelihood of it generating production losses<sup>67</sup>.
- **“Dynamic” curtailment systems**, triggering the stoppage of the turbines in reaction to the real-time detection of bat activity, are innovative solutions for reducing bat mortality. Nevertheless, their capacity to effectively reduce mortality risks is less solidly documented than for static regulation modes. A study published in 2022 about a wind farm in Wisconsin (United States) showed that a real-time curtailment system led to a significant drop in mortalities compared to unregulated wind turbines<sup>68</sup>, although it resulted in substantial production losses compared to wind turbines regulated using conventional curtailment. However, the data in this study were collected in 2015, since when detection technologies and reaction algorithms have been improved. Dynamic curtailment is dependent on detection quality, data processing and the reliability of automated systems<sup>69</sup>. Currently, this “reactive” regulation mode is less well developed and mature than “passive” predictive or preventive measures. Additional research is therefore required to standardise dynamic regulation approaches and assess their large-scale and long-term performances.

Regulating the operation of wind turbines is therefore essential for reducing their impacts on bat populations. Defining a curtailment system based on fixed wind and temperature thresholds generally reduces mortalities but is insufficient for covering the risk associated with the diversity of sensitive species and flight behaviours. Using multicriteria algorithms produced from more detailed activity models is a promising and more efficient approach with tools validated in scientific publications, which should encourage their generalisation. While real-time acoustic detection technologies could refine the regulation of wind turbines and avoid “pointless” turbine stoppages, which result in sometimes significant production losses, they do not nevertheless currently seem capable of replacing predictive curtailment.

A link can be established between certain activity metrics and bat mortality. It remains partial, due to bias in acoustic detection and finding corpses, together with the difficulty of modelling the mortality risk associated with specific behaviours (social interactions, courtship ...), which underlines the importance of enhancing and refining scientific knowledge. The most effective and least costly approach currently appears to be using models that predict activity based on various measurable variables<sup>70,71,72</sup>. The integration of real-time acoustic data could enable curtailment to be adapted to unpredictable events and optimise predictive regulation models. Concretely, wind turbines could be operated during certain periods corresponding to predictive curtailment parameters if no activity is detected around the turbines, on condition of transparent validation of the acoustic detection systems’ performances.

67. Behr *et al.*, 2017.  
68. Rabie *et al.*, 2022.  
69. Rabie *et al.*, 2022.

70. Korner-Nievergelt *et al.*, 2013.  
71. Behr *et al.*, 2017.  
72. Barré *et al.*, 2023.

## REDUCING BIRD STRIKE RISKS THROUGH PREDICTIVE CURTAILMENT MEASURES

**D**uring the operating phase, wind farms are a strike risk for avifauna. In France, it was estimated in 2017 that on eight monitored onshore wind farms, wind turbines killed between 6.6 and 7.2 birds per year, including 81% belonging to protected species with a worrying conservation status<sup>73</sup>. These figures will be updated by means of more robust estimations from the APOCOPE programme, carried out until the end of 2026 by the consultancy Ouest Am' in partnership with the National Museum of Natural History. For certain birds, these strikes can affect their population dynamics and accentuate their vulnerability to extinction risk.

The first solution for mitigating impact risks consists in avoiding the construction of wind farms inside or close to ecologically sensitive areas<sup>74</sup>, with priority conservation issues (protected areas, migration routes, habitats of protected species, woodlands or wetlands, etc.)<sup>75</sup>. Then, one of the ways to work on reducing impacts is to improve understanding of the situations and factors leading to strike risk. Birds can adopt very variable flight behaviours in function of the species, age and sex of the individual, geographical location, period of the year or time of day, or meteorological conditions. Anticipating – and hence reducing – mortality risks therefore requires a thorough understanding of species' ecology and their interactions with wind farms.

Birds likely to suffer wind turbine strikes (blades and tower) may be nesting locally, on migration or overwintering. They are sometimes incapable of detecting the rotating blades or tower in time, due to their visual field and position compared to the wind turbine, visual acuity and contrast perception capacity, poor visibility conditions, having their attention focused on a particular activity, or the simultaneous combination of several of these reasons<sup>76</sup>. Very many species migrate at night or are capable of flying in severe meteorological conditions, which significantly lessens their capacity to anticipate the presence of unexpected obstacles such as wind turbines. In addition, birds' flight paths often follow linear landscape elements such as valleys, rivers, mountain passes and coastlines which are very often windy areas where it is therefore likely that wind turbines will be set up, thus increasing strike risk. Many land birds, including small passerines, also follow migration routes over the sea (Channel, Mediterranean, Atlantic Ocean), and like seabirds are therefore potential victims of offshore wind farms. France is crossed by major migration routes for the nesting birds of the whole of Europe, which may follow continental, coastal or high-sea corridors to migrate from higher latitudes (Scandinavia, British Isles and the rest of western Europe) to their wintering grounds (southern Europe and Africa) and vice versa.

73. Marx, 2017.

74. In accordance with the positions of the IUCN French Committee and the worldwide IUCN.

75. Ecodesign of onshore wind farm projects, OFB Technical Portal.

76. Blary *et al.*, 2023.

Griffon Vulture © Paul Bonfils

The impact of wind farms on avifauna has led to the setting up of various techniques to reduce mortality, some of which benefiting from solid feedback on experience while others are still at a more experimental stage. Two main approaches emerge: the first, referred to as “scaring”, aimed at generating an avoidance reaction by birds close to wind turbines (whose efficacy is currently rather controversial), and the second consisting in curtailing wind turbines by stopping the rotation of the turbines in order to reduce strike risk. As for bats, stoppage may be triggered under certain conditions defined in advance, or as a direct reaction to a bird approaching the wind turbines; also referred to as “static” or “dynamic” curtailment. The following feedback on experience illustrates the subject of static curtailment in wind power projects facing bird conservation issues.

## DETERMINING THE CURTAILMENT PLAN AND FEEDBACK ON EXPERIENCE

The interest of static, or predictive, curtailment is the certainty of its effectiveness when it is implemented: stopped wind turbines present a considerably lower strike risk. The issue for this measure is optimally defining the curtailment period. Stopping the wind turbines for a very long period will cause economically unsustainable production losses for the operator, while curtailment for excessively short periods will not ensure the survival of a satisfactory proportion of passing birds. This question therefore involves identifying the impact on electricity production of the stoppage periods required to protect the avifauna. If the project’s profitability is not ensured, either its location should be reconsidered, or it should not be authorised. The curtailment plan needs to be adapted, case-by-case, to the issues of the site revealed by the nature surveys and environmental impact study. Some wind power projects are principally a threat for migrating birds while others are a greater risk for birds nesting nearby or using the site as a functional habitat.

### PROTECTION OF AVIFAUNA IN AGRICULTURAL CONTEXTS

In areas under cultivation, reducing the impacts of wind farms may involve adapting the turbines’ operating periods regarding agricultural work that generates highly attractive contexts for sensitive birds. Raptors such as kites, harriers, buzzards and falcons particularly frequent fields that have been ploughed, reaped, harvested or subjected to any other work that uncovers the soil and therefore increases the accessibility of their prey (micromammals, insects, worms ...)<sup>77</sup>. Once again raptors’ activity from one wind farm to another depends on differences in crop rotation, agricultural practices, landscape contexts and the sets of species present. Agricultural curtailment therefore needs to be adapted to the local context, after thorough analysis of the agricultural practices and the frequentation of fields by birds.

77. KNE, 2025.

## FEEDBACK ON EXPERIENCE: AGRICULTURAL CURTAILMENT ON A WIND FARM OPERATING IN YONNE

The wind farm, put into operation in 2022 by the company Engie Green in the Yonne department, has six wind turbines and a total power of 18 MW. This project, set up on 1.7 hectares of field cropland, was initially intended for 20 wind turbines but was revised to avoid the areas with highest-priority issues, with woodland and hedged habitats home to sensitive species such as the Booted Eagle or certain bats, and limited to six machines. To reduce their impact during the operating phase, the project leader implemented an “agricultural curtailment” plan: the wind turbines are stopped during reaping and stubble-ploughing in July and August in response to the issue of protecting Black and Red Kites frequenting the site. When this type of measure is implemented, it could be pertinent to set up specific monitoring to assess its efficacy better, especially since there is still little scientific literature on this subject.

## PROTECTION OF MIGRATORY AVIFAUNA

When a risk for migrating bird populations is identified, for example on wind farms set up in uplands or passes, along the coast or offshore, identifying the periods and conditions leading to the greatest risks is the key to defining the most appropriate curtailment plan.

## FEEDBACK ON EXPERIENCE: CURTAILMENT FOR THE COMMON CRANE ON A WIND FARM IN NIÈVRE

When the development of a six-turbine wind farm in the Nièvre department was launched, the impact study revealed that it was situated right on the migration corridor of the European population of Common Crane, a very large and remarkable wading bird of major heritage importance. While they habitually fly at high altitude, cranes sometimes fly quite low in poor meteorological conditions or close to their migration stopovers. The project developer therefore sought a way to limit strike risks, for which a specific protocol was devised in concertation with LPO Bourgogne-Franche-Comté and DREAL. During the prenuptial and postnuptial migration peaks, the LPO publishes a daily bulletin on Common Crane activity, drawn up based on the observations of the Common Crane Network and meteorological conditions. Since the wind farm was put into operation in 2013, this bulletin has been transmitted to the operator’s on-duty team, which can stop the turbines in the event of an alert until the LPO gives the go-ahead. Mortality monitoring was carried out in 2014, 2015, 2016, 2017, 2023 and 2024 with no Common Crane corpse being found. This measure is made possible by means of an annually renewed partnership between LPO Bourgogne-Franche-Comté and the wind farm operator, and therefore requires the existence of a competent local association with sufficient technical and human resources to carry out such long-term monitoring.



Offshore, the development of wind farms enables more stable and stronger wind resources to be accessed than on land, with the setting of larger turbines due to the lesser landscape issues. The question of avifauna protection is crucial because flows of seabirds and migratory landbirds are sometimes very intense at sea. Given that the areas where wind farms can be set up are predefined by the State and that the distance from the coast is limited by technical constraints, curtailment of wind farms is an appropriate measure, especially since migration episodes can be highly concentrated according to favourable meteorological conditions<sup>78</sup>.



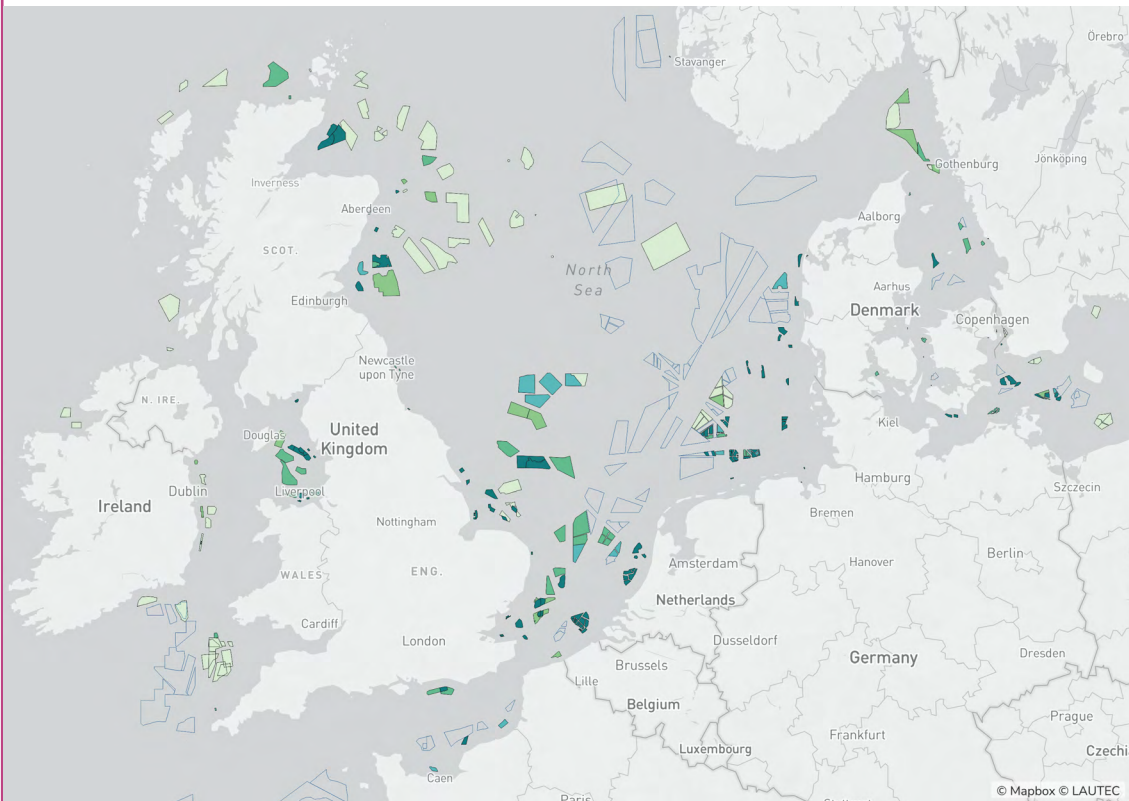
Iles d'Yeu and Noirmoutier wind farm © Paul Bonfils

To characterise the offshore migrations of birds and bats together with the functions of coastal and high-sea areas for seabirds throughout the year, the MIGRALION and MIGRATLANE projects are piloted by the French Biodiversity Office on all three French seaboards. They aim to fill the gaps in knowledge about the use of maritime areas by flying fauna in the Mediterranean, Atlantic and Channel/North Sea, to limit and better understand the impacts of human activities including the development of wind farms. To achieve this, measurement and monitoring campaigns were launched, using a broad range of techniques: acoustic and visual monitoring offshore and from the coast, airborne campaigns, remote sensing of 40 bird species, ornithological and meteorological radars. While the project MIGRALION ended in 2025, MIGRATLANE will continue until 2027.

78. Newton, 2010.

## FEEDBACK ON EXPERIENCE: DEVELOPMENT OF A CURTAILMENT MODEL IN THE NORTH SEA

A considerable surface area of the North Sea is occupied by operating or future wind farms, notably upstream of the Dover Strait, a corridor for a significant proportion of European migratory flows. The curtailment issue is therefore particularly important for significantly reducing the impact of multiple wind farms on migratory bird populations.



Map of offshore wind power projects under development and operating in the North Sea (Sea Impact, 2025)

A research team from Amsterdam University established a predictive model of bird migration intensity off the coast to enable the Dutch government, in function of meteorological forecasts, to anticipate by 48 hours the curtailment of wind farms to limit strikes during migration peaks<sup>79</sup>.

This model was developed by cross matching the migration monitoring data collected over five years by a radar placed in a wind farm 23 km from the Dutch coast with various factors influencing the intensity of migratory flows (related to species' phenology and the meteorological context). Analysis of the data showed that the most influential variables are phenological parameters (day of the year and time of day) and wind speed. In spring, migratory flows principally depend on phenology, breeding birds fly north as fast as possible to reach their nesting grounds. In autumn, meteorological conditions play a greater role with birds tending to wait for a favourable wind to fly southward. For the control migration flights used to test the

79. Bradaric et al., 2024.

model's calculations, in spring 2022 and autumn 2020, half of the total migratory flow occurred over 18 and 26 hours respectively. The model's simulations estimate that if the turbines had been stopped for the hours of highest migration intensity to protect 50% of the birds, the production loss would have been the equivalent of 0.12% of the annual total. With larger datasets, it could therefore be envisaged, in the future, to refine the model to more precisely predict the times of migration peaks. This would enable wind farms to be stopped to effectively protect a high proportion of migrating birds while anticipating variations in production by the network and limiting the impact on the facilities' profitability.

In France, there is currently no generalised regulatory curtailment measure for all offshore wind farm projects. On a pilot floating wind farm in the Gulf of Fos in operation since 2025, the prefectural authorisation decree specifies the conditions of a stoppage plan for the machines during first the five years of operation. The operator is obliged to interrupt the operation of three of the wind farm's turbines for a cumulated annual duration of 500 hours, spread over six consecutive nights in April and seven consecutive nights in September, determined by means of radar data on migration from the coast. This experimental measure is assessed annually based on video observations and a radar set up on the wind farm, thus enabling the details of the protocol to be adjusted after the five-year trial<sup>80</sup>.

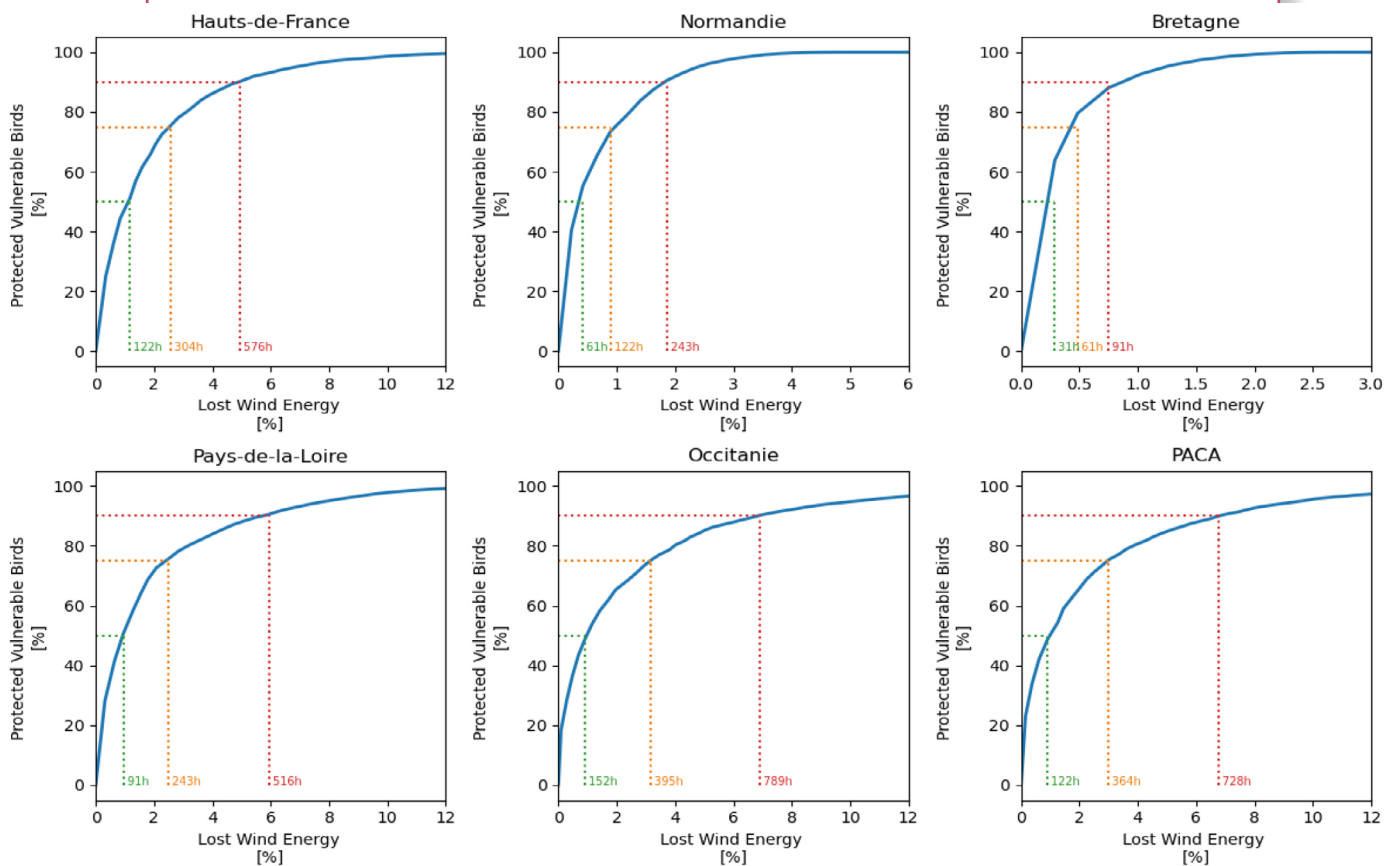
The aim of the SEMAFOR project, led by France Energies Marines, is to develop a real-time avifauna surveillance tool via Météo France's network of meteorological radars, and compile a predictive model of migratory bird flows for Metropolitan France. As with the Dutch models, the results of this project show that most migration in France often occurs over relatively short periods. Estimations of production loss linked with migration flows show that protecting 50% of nocturnal migratory species would involve reducing wind power production by approximately 1% on average, or 2.5% to cover the migration period of 75% of birds.



Eurasian Curlews © Paul Bonfils

80. Prefectural Decree 82-2017-EA, 2019.

These figures differ significantly for each region, notably in Brittany and Normandy, where flows of nocturnal migratory species detected by meteorological radars are lower than in other regions; the most important flights are therefore reduced to a few hours per year. In regions where migratory flows are more sustained and constant over a season, as in Occitanie, the conservation of the same proportion of birds would be obtained with a wind turbine stoppage time approximately three to five times higher<sup>81</sup>.



Relationship between proportion of birds protected and proportion of wind power lost annually. The percentage of energy power is given for three protection scenarios of 50%, 75% and 90% of avifauna at risk (SEMAFOR project, 2024).

The curtailment plan can therefore be defined based on prediction models of migratory flows in function of meteorological conditions and species phenology. The major issue is therefore currently the mass collection of flight data to refine these models and enable them to more precisely calculate the most strategic periods for curtailing wind farms. Radar technology provides interesting avenues for enhanced understanding of large-scale migration phenomena, planning wind power development, identifying the wind farms most at risk and helping the sector to set up appropriate curtailment measures. Surveillance of migration phenomena could also enable wind power operators to be directly alerted about mass movements of birds so as to trigger the stoppage of turbines.

81. Roy et al., 2024.

## AUTOMATIC DETECTION SYSTEMS (ADSS) FOR AVIFAUNA

**W**ith a view to optimising the regulation of wind turbines to limit their curtailment only to periods of proven presence of birds specifically intended to be protected, detection-reaction systems, or automatic detection systems (ADSS), for avifauna are deployed on certain wind farms. They are used to reduce the mortalities of “heritage”, often large birds (raptors and big wading birds).

Known detection systems can currently be classified into four main families: 2D optical systems (in which detection and classification are performed by analysing pixels), 3D optical systems (enabling more precise assessment of the distance and pathway of detected objects), radar systems (with a higher range than optical systems, but incapable of precisely identifying species), and systems combining more than one technology (principally a long-distance radar and a shorter-distance optical device).

The operation of ADSS is based on image recognition and analysis software, now generally using artificial intelligence, enabling detected objects to be classified to determine the appropriate reaction. This depends on the definition of a list of species to be protected, produced in function of the issues of each wind farm, sensitivity of species and their size (the ADSS need to be capable of detecting them). The choice of species targeted by detection-reaction systems is not based on purely regulatory criteria (most species suffering from wind turbine strikes have equivalent protection status) nor purely scientific ones (the choice of protected species does not always depend on the vulnerability of their populations to wind-power mortality<sup>82</sup>).



Greater Flamingos © Paul Bonfils

82. Chambert & Besnard, 2021.

## FEEDBACK ON EXPERIENCE

### **VOLUNTARY INITIATIVE TO ASSESS THE PERFORMANCES OF ADSs DEPLOYED ON SEVERAL WIND FARMS BY A WIND POWER OPERATOR**

In late 2024, the renewable energies producer Valeco set up its hundredth ADS since the first wind turbine it equipped in 2017. Currently, its 106 wind turbines are fitted with equipment from five manufacturers, with more than 500 video cameras able to detect medium- to large-wingspan birds and trigger acoustic scaring or turbine stoppage. The Valeco initiative involves submitting the ADSs to series of tests to check their performance, reliability and data traceability. To do so, the operator uses drones imitating birds in flight to verify that they are detected, the sending of the stoppage order and its processing for the equipped wind turbine. The systems are also tested under real conditions, by means of monitoring by ornithologists to ensure that the birds flying close to equipped wind turbines are correctly detected and protected - 114 sessions, i.e., more than 770 hours of monitoring, have been carried out on 8 wind farms. Finally, tests on slowing turbines in response to signals sent by the ADSs have been carried out at wind forces involving the highest rotation speeds in the operating range of the wind turbines; according to Valeco, the rotor of all equipped machines goes from 17 to 2 revolutions per minute in approximately 30 seconds. With its numerous operating wind farms, Valeco has concrete feedback on experience. Consider the example of a wind farm in the Pyrénées-Orientales department, regularly frequented by protected heritage raptors, where four corpses were found during mortality monitoring between 2018 and 2020 (43 inspections per year). In the face of this situation, Valeco decided to fit the ten wind turbines with ADSs. The images viewed and 130 mortality monitoring inspections carried out since they were set up have not yet detected any raptor strikes.

Nevertheless, in general ADSs are not sufficient for eliminating mortalities. In Haut-Languedoc, a wind farm caused the death of a Golden Eagle in 2023 despite the video camera set up on the machine responsible and the low residual rotation speed of the turbine. Also in the Hérault department, all 31 wind turbines of another wind farm are fitted with ADSs but this did not prevent several tens of strikes involving protected raptors, in particular Lesser Kestrels and Montagu's Harriers. Moreover, the mortalities observed on these two wind farms resulted in financial and legal sanctions<sup>83</sup>.

Finally, voluntary assessments of ADS performances, while they may indicate efforts for improvement and transparency on the part of wind power operators, nevertheless do not provide clear conclusions on the systems tested. Such assessments are often based on heterogeneous protocols and implemented under optimum detection conditions, with sample sizes sometimes too low to gauge statistical uncertainties.

83. By the judicial tribunal of Montpellier, decision made 7<sup>th</sup> April 2025 for the Aumelas wind farm and 9<sup>th</sup> April 2025 for the Bernagues wind farm.

## PERSPECTIVES OFFERED BY TECHNOLOGICAL ADVANCES FOR PROTECTING FLYING FAUNA

Technological progress concerning ADSs can be illustrated by the example of the IdentiFlight system developed by the American company Boulder Imaging, which has specialised in imaging technologies since 1995. In 2013 it launched a research and development programme to respond to the challenge of conserving Golden Eagles and Bald Eagles faced with the development of wind power in the western US.

The first commercial version was launched in 2017, aimed at detecting large raptors and performing selective dynamic curtailment minimising the production losses for wind farm operators. Over the years, the company has made improvements to both cameras and artificial intelligence algorithms, increasingly enabling smaller and faster-flying birds to be detected, with enhanced monitoring and more precise calculation of flight paths.

As from 2024, the fifth version of the IdentiFlight system was presented as capable of identifying and monitoring small fast-flying raptors, then in 2025 an infrared detection module was added for flocks of migrating passerines and bats so as to be functional at night. Nevertheless, the detection of small animals, often flying quickly along sometimes difficult-to-predict flight paths, remains a great challenge and is currently not satisfactory for achieving a significant reduction in mortalities.

Currently, the IdentiFlight system is fitted to approximately 1100 wind turbines on 36 wind farms in the world, and the performance of its classification algorithm is recognised, emphasising the precision of its identifications to limit false positives, i.e., “erroneous” triggering of the turbine stoppage mechanism. While several studies suggest a sizeable reduction in the number of large raptor mortalities by implementing this system<sup>84</sup>, questions concerning their statistical robustness<sup>85</sup> underline the need for rigorous and standardised analysis protocols to demonstrate the real capacity of this system, currently among the most advanced, to significantly reduce mortalities.



84. McClure *et al.*, 2018, McClure *et al.*, 2021 and McClure *et al.*, 2022.  
85. Huso & Dalthorp, 2023.

## EFFICACY OF THE MEASURES

### Interesting solutions whose performances need to be assessed on a large scale according to standardised scientific protocols

Real-time bird detection technologies are likely to reduce the strike risk for certain target species, but currently most of these systems are not developed in a coordinated manner and still do not benefit from a robust assessment of their real efficacy. These devices have been subjected to various assessments carried out by the suppliers themselves, consultancies mandated by wind power operators, associations or government agencies in several countries, from which it is difficult to draw clear conclusions. These studies are based on heterogeneous and sometimes unsatisfactory protocols, which do not enable comparative analysis of the efficacy of these systems<sup>86</sup>. Moreover, they are often carried out under optimum detection conditions, not covering the diversity of real situations<sup>87</sup>, especially given that the riskiest conditions for birds (poor visibility, strong wind) are also the least propitious for the correct operation of ADSs. Globally, it is unlikely that a single system will be able to reduce the strike risk to a sustainable level for the bird populations most sensitive to wind power risks, notably due to the diversity of the impacted species in terms of flight behaviour or morphology<sup>88</sup>.

Understanding the performance of detection-reaction systems requires measuring their capacity to effectively reduce mortalities. To do so, mortality monitoring should be performed before and after they are fitted, and compared with control sites. However, bias in the detection of corpses complicates the assessment of real mortality rates on wind farms<sup>89</sup>. Numerous factors influence the number of mortalities observed during monitoring: the inspection perimeter around each tower (birds are projected far from the blades or do not die immediately), ability to detect corpses on the ground<sup>90</sup>, frequency and number of visits to the site (corpses removed by predators). It should be noted that mortality monitoring is additionally challenging at sea, where birds' corpses cannot be retrieved because they fall into the water.

Standardised scientific protocols therefore need to be devised to assess the performance of ADSs. This is all the more crucial given that these systems are currently highly sought after and much deployed on wind farms. For this reason, initiatives have been launched to define a validation framework for ADSs based on their performances in real conditions.

In Germany, the government has recognised the use of ADSs to reduce the strike risk of birds with wind turbines (Article 45b of the federal Law on Nature Protection), provided they respond to strict performance criteria established by the German Resource Centre for Nature Conservation and Energy Transition (KNE). To be authorised on wind farms, ADSs need to provide spatial cover of at least 75%, the most complete possible temporal cover, a minimum detection range linked to the speed of the species considered and turbine stoppage time, a detection rate of at least 75% or even 90% in the event of particular issues, and a minimum bird classification performance by algorithm of 75%, then 90% within a close radius of the wind turbines<sup>91</sup>.

86. Huso & Dalthorp, 2023.

87. Corbeau et Besnard, 2021.

88. VULNEO, 2025.

89. Sand, Normand, Kerbiriou *et al.*, 2024.

90. Dogs, for example, show much better detection performances (Smallwood, 2020).

91. Reichenbach, M. *et al.* (2023).



Red Kite © Paul Bonfils

KNE also specifies requirements in terms of assessment: multi-season campaigns carried out under real conditions by independent consultancies, comparison with control data (observers, remote sensing...) and certification by an independent organisation. For example, since 2021 the IdentiFlight system has been subjected to studies in various *Länder* (German administrative divisions comparable to French regions) to be homologated in Germany, targeting priority species such as the White-tailed Eagle and Red Kite. The tests showed performances compliant with the KNE criteria, with detection and classification rates between 90 and 99% in function of the site, enabling its implementation for wind power projects. The *Länder* can also define rules for authorising ADSs on their territory; for example, the *Land* of Schleswig-Holstein implemented a framework in 2023 obliging wind power project developers to accompany their authorisation application by an external assessment report on the ADS demonstrating its efficacy according to the KNE criteria, together with its working and operating framework.

In France, an assessment protocol was developed in the framework of the project "MAPE", meaning "bird mortality in operating wind farms", led by CNRS (National Centre for Scientific Research), CEFE (Centre for Functional and Evolutionary Ecology) and MSH Sud (*Maison des Sciences de l'Homme de Montpellier*) between 2020 and 2025. This project brought together researchers, NGOs, the wind power sector and public administrative bodies around several working themes, notably understanding the causes of strikes and devising an assessment framework for ADS performances. The assessment of each system needed to include its bird detection capacities, calculation of their flight paths, and a classification of species and their reactivity to a broad range of conditions<sup>92</sup>. A standardised methodology for characterising the efficacy of ADSs is crucial for helping wind power operators to select the most appropriate system for the needs of their wind farms<sup>93</sup>, given the heterogeneity of the systems available on the market. The reference base for validating them is based on performance criteria such as the minimum distance at which the ADS needs to be capable of detecting birds to effectively reduce their mortality. This question was the subject of specific work resulting in the tool "EolDist", which calculates the precau-

92. Bollester, C. et al. (2024).

93. Corbeau A. & Besnard A., 2021. *Les systèmes de détection-réaction dans les parcs éoliens, un moyen de réduction des mortalités aviaires. Principes et conseils pour une bonne évaluation.* Projet MAPE.

tionary detection distance according to the species concerned, its behaviour (local or migratory flight), type of wind turbine set up, wind speed, and desired residual rotation speed of the rotor when the bird arrives nearby. Because numerous ADSs are not currently effective enough, these minimum detection distances caused the wind power sector to question the results of the MAPE programme. As a complement, the ADEME and OFB therefore launched the project “ADSs+” with the double objective of offering ADS suppliers a voluntary certification process for performances achieved by systems when they leave the factory and defining a large-scale operational assessment process for the performances of ADSs set up on wind farms.

Ultimately, ADS technologies can be interesting solutions provided they respond to performance requirements founded on long-term survival criteria of populations taking into account all cumulated impacts, and as long as they are combined with other devices. A robust approach could typically consist in fitting a wind farm or set of wind farms with radar technology for large-scale detection, video cameras and acoustic sensors for close coverage and deploying impact sensors on each turbine. Currently, the development and rapid evolution of ADS technologies need to be accompanied by a systematised assessment of their performances and efficacy for them to transparently confirm and demonstrate their utility in reducing impacts.

In addition to their function in regulating wind turbines, ADSs may be an interesting alternative to traditional methods of studying avifauna (direct observation or satellite tagging). They automatically record numerous data about birds’ presence and behaviour on wind farms worldwide, in a broad variety of geographical and landscape contexts. These data could be used to better understand the conditions and causes of bird strikes, linked with wind turbine operating parameters or more broadly environmental conditions. For example, the company Biodiu-Wind, developer of a 2D optical ADS, analysed the strikes that occurred on the 750 wind turbines fitted with its system in Europe to study the relationship between rotation speed and raptor mortality. The CNRS studied the environmental and behavioural causes of bird strikes in the framework of the MAPE programme by using data from several 2D and 3D systems on eleven wind farms in the agricultural plains of the eastern half of France. Analysis of the data gathered by these ADSs showed that the exposure of birds to strikes with wind turbines depends on the period of the year, with peaks during the migration seasons in spring and autumn, and that their vulnerability is also high in summer, with resident birds frequently using wind farm sites as hunting or nesting grounds. These results are consistent with other studies based on other methods, demonstrating the pertinence of using ADSs as tools in their own right for studying avifauna on wind farms. Improvement in their detection capacities could enable species currently excluded from the analysis to be studied, such as nocturnal or small birds, which make up the majority of wind turbine victims at national scale. Moreover, their flight behaviours and response to meteorological conditions being very different from large species, better knowledge of their strike risks should be a priority in formulating recommendations relevant to a broader range of species.

## REDUCING UNDERWATER NOISE DURING THE WORKSITE PHASE IS CRUCIAL IN OFFSHORE WIND POWER PROJECTS

Underwater noise generated by human activities has greatly increased in the oceans in recent decades, resulting from numerous sound sources such as maritime transport, seismic surveys or the drilling and driving of piles used in various industries, notably the energy sectors. These phenomena can cause major disturbances to marine fauna, from changed behaviour to temporary or permanent, sometimes lethal physiological lesions. These effects are well known for marine mammals, which very frequently emit sounds to communicate, navigate and hunt, but also affect fish, the benthos and diving birds. Dolphins and porpoises are cetaceans that are common off European coasts but suffer from a wide range of pressures including maritime transport, industrial fishing, pollution and also underwater noise. These sensitive and priority conservation-issue species are therefore impacted by various pressures caused by human activities including the worksites of offshore wind farms. All cetaceans are fully protected by law in France and covered by a national action plan initiated in 2018.

Research and feedback on experience concerning marine renewable energy projects highlight the impact of noise linked to wind farm works, notably the geophysical campaigns prior to their construction and operations to prepare substrates and lay foundations, which can result in behavioural disturbances, lesions or even the death of marine animals<sup>94,95</sup>. Wind turbines may be floating or placed on the seabed. The foundations of the latter differ in function of the depth, nature of the seabed and economic constraints. "Monopile" foundations are the most commonly used due their simple manufacture and low cost. Piles may be driven, i.e., banged into the ground with a hydraulic hammer, used more frequently with loose substrates, or bored into the seabed for rocky and hard substrates. The driving technique produces louder sound emissions than boring<sup>96</sup>. Floating wind turbines are fixed to anchorages on the seabed. Setting up this type of structure generates less noise than boring or driving foundations.

Several approaches can be implemented to reduce the sound emissions linked to offshore wind farm construction works, modifying either the sound level at its source or the propagation of noise in the water. Adapting the foundation type and technique may be a means of limiting sound emissions, but this choice is generally dictated by the project's technical characteristics and the nature of the seabed<sup>97</sup>. In addition, there are several techniques for limiting the propagation of sound in the water by enveloping the sound source in absorbent physical barriers and dispersing a proportion of the sound waves: bubble curtains, nets full of air-filled balloons or casings. These methods are the subjects of research and innovation to investigate them and improve their efficacy.

94. Bailey *et al.*, 2014  
95. UICN France, 2014.

96. OFB, 2023.  
97. Biotope, 2025.

## FEEDBACK ON EXPERIENCE

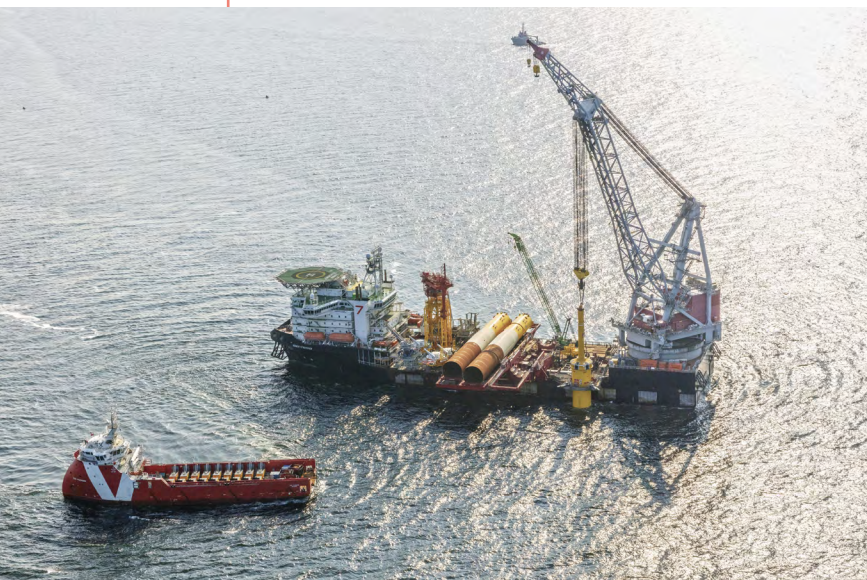
Several countries have defined regulatory maximum noise thresholds for offshore wind power constructors, e.g., 190 decibels (dB) at 750 metres from the noise source in Germany or 185 dB at 750 metres from the noise source in Belgium. In other countries where there is still no regulatory sound emission threshold, as in France, measures can nonetheless be implemented to reduce the impact of works on marine biodiversity.

### DESIGN OF A PROJECT INCLUDING NOISE ABATEMENT MEASURES

In 2018 and 2019, the Swedish operator Vattenfall won the call for bids concerning the four zones of the *Hollandse Kust Zuid* wind farm, off the Netherlands coast, situated between 18 and 35 kilometres from the coastline. This wind farm with a power capacity of 1.5 GW consists of 139 turbines set up on sandy and sedimentary seabeds at depths of between 17 and 28 metres. This type of substrate involves using the technique of driving foundations, generating considerable sound pollution. To limit the impact of these works, the noisiest operations were scheduled outside the periods with the greatest presence of marine mammals, in late winter and spring, periods determined during project's initial status surveys and preceded by a scaring measure to drive the animals away. These measures were accompanied by the setting up of a "double big bubble curtain" (DBBC) and monitored using hydrophones to measure noise levels and assess the presence of marine mammals. The regulatory underwater noise limits applied to this project were set at 173 dB between June and August, and 175 dB between September and December 750 metres from the driving site.

To set up each 8-metre-diameter monopile, the acoustic forecasts of the Netherlands Organisation for Applied Scientific Research (TNO) estimated that the raw sound exposure level without noise abatement measures would be approximately 183 dB at 750 metres. In a scenario with noise abatement (DBBC), the forecast noise levels

were 169 to 170 dB at the same distance from the pile. The data from the monitoring of the first construction campaign showed that the mean maximum noise level recorded was 161.5 dB with highest value being 166 dB, which remains below regulatory levels. Moreover, some of the highest noise levels were due to a fault in the device; an air tube that had stayed on the seabed for several weeks was partially colonised by marine organisms, blocking several airholes.



Construction of an offshore wind farm © Vattenfall

## MONITORING NOISE LEVELS ON A PROJECT UNDER CONSTRUCTION

On the offshore wind farm off the coast of Côtes d'Armor in Brittany, operated since 2023 by the consortium Ailes Marines, some of the 62 wind turbines are set on a very hard granitic substrate, which requires the boring technique, and others on a looser substrate where driving the piles was initially planned. Due to strong currents in the bay and the resulting difficulty of mitigating sound propagation (the main technique used at that time, the bubble curtain, being affected by currents), the constructor decided to bore all the wind farm's foundations - this technique being less noisy than driving.

Underwater noise was measured over the two years of construction using a buoy continuously recording the surrounding acoustic landscape with real-time monitoring. To take into account the various geological characteristics of the seabeds, noise was monitored for 9 of the 62 foundations bored, including three in the north of the wind farm on rock outcrops and sub-outcrops, three in the centre on gravel with seashell debris and three in the south on a substrate of sand and gravel. The outcomes of the 2021 and 2022 environmental construction measures showed that the sound levels recorded did not correlate to the type of substrate or the drill rotation speed. However, the noise generated by the works was principally associated with the setting up of the boring vessel. The trenching operations for the electrical connections produced continuous noise similar to that emitted by the vessel using its dynamic positioning system. Noise levels in the water column are globally comparable to the sound emissions of a large transport vessel such as a container ship.

## EFFICACY OF THE MEASURES

### Variably effective measures to be improved to stretch their limits

The method of setting foundations in the seabed being generally dependent on geological and technical criteria<sup>98</sup> and the alternative techniques to pile driving still being underdeveloped<sup>99</sup>, reducing the propagation of sound waves appears as a crucial approach for reducing the impacts linked to construction works on offshore wind farms. The performance of the various techniques for mitigating the propagation of noise depends on numerous factors, notably the characteristics of the driving process and the devices implemented. In addition, not all sound frequencies are abated in the same way.

The bubble curtain, consisting in pressurised injecting air into one or more rings of perforated tubes around the pile, is the most commonly practised technique, and benefits from its maturity. It enables substantial reductions in noise, measured at between 10 and 25 dB in function of the project, with maximum mitigation between 500 Hz and 2 kHz<sup>100</sup>. It is a measure which has proved effective for reducing the impact of driving on porpoises<sup>101</sup>. Nevertheless, this technique requires considerable amounts of energy to inject large volumes of compressed air, and its efficacy is marred by currents, which disturb the rising bubbles<sup>102</sup>.

98. Biotope, 2025.  
99. CNRS, 2023.

100. Lucke *et al.*, 2011.  
101. Dähne *et al.*, 2017.

The casing technique, consisting in surrounding the pile by a steel tube filled with air, reduces the sound emissions of driving operations. The reflection between the air, steel and water provides roughly the same acoustic insulation as the bubble curtain. The steel casing can also not be filled with air, referred to as “coffered”, which can produce similar performances under certain circumstances<sup>103</sup>. Nevertheless, the difficulty of setting up these devices and the limited depth of water are obstacles to their utilisation.



Implementing a double bubble curtain © Vattenfall

To overcome the disadvantages of the bubble curtain, in particular when sea currents are too strong and avoid the continuous use of air compressors, nets fitted with elastic air-filled balloons and foam elements can be deployed around the pile. This type of device, called a “hydro sound damper” (HSD), also has the advantage of controlling the frequency of maximum sound abatement by adjusting the diameter of the balloons<sup>104</sup>. The identified disadvantages of this method are that the system is costly and requires good meteorological conditions to set it up.

Other methods are under development, such as inflatable membranes, where the pile is surrounded from top to bottom by a membrane which, once inflated with air, insulates by impedance like the steel casing. Currently at the prototype stage, this technology is being supported by the ADEME ecological transition agency until the first system operational under real conditions is completed.

In Belgium, the effect of noise abatement on pile driving has been studied on several offshore wind farms<sup>105</sup>. The acoustic monitoring data of Harbour Porpoises, a cetacean often chosen as a control species for its sensitivity to underwater noise, were exploited to assess their avoidance behaviours of the construction zone. They showed that pile driving did disturb the animals within a radius of 20 to 25 km around the noise source. When the operators implemented a double bubble curtain, the disturbance seemed to lessen, and also be limited to a radius of approximately 10 km.

Reducing the impacts linked to the noise of pile driving on offshore wind farms also involves complementary measures to sound emission mitigation. Firstly, worksites need to be planned outside the most sensitive periods for fauna, determined in function of the issues of each project after the environmental impact studies. Then, the presence of marine mammals close to a worksite zone can be assessed before and during the works by onboard observers or using underwater microphones called hydrophones. This surveillance ensures that the animals are sufficiently far away before the pile driving starts or that operations are interrupted if marine mammals enter the exclusion zone. In addition, acoustic scarers (pingers) can frighten sensitive animals away from the works zone.

102. Matuschek & Betke, 2009.  
103. Koschinski & Ludemann, 2013.

104. Elmer & Saverly, 2014.  
105. Rumes *et al.*, 2021.

Finally, progressive building up of pile driving, commonly called “soft start”, is aimed at giving time for the animals to move away and avoid auditive lesions. In Europe, these approaches are very widely used to protect marine mammals, particularly dolphins and porpoises, which are often present in projects’ study areas. It should be noted that, while the efficacy of pingers has been demonstrated, especially for porpoises<sup>106</sup>, habituation phenomena can also be observed<sup>107,108</sup>. Finally, it seems that acoustic deterrents used for seals greatly affect porpoises, even more than pile driving when a bubble curtain is set up, which would justify reassessing the characteristics of the sounds emitted<sup>109</sup>.

To analyse and measure the impact of noise on marine fauna it is necessary to understand the role and workings of animals’ sound perception, but knowledge remains very incomplete concerning numerous taxa, notably marine invertebrates. The effects of anthropic noise on the various stages in invertebrates’ life cycles under real conditions are still little documented; there are few studies where marine invertebrates are exposed to real anthropic sound sources (boat noise, pile driving, seismic surveys ...) under real conditions. Moreover, the auditive capacities of seabirds and sea turtles are still little known. It is also necessary to extend impact studies to food networks, where impacts on the lowest levels must certainly have consequences for the whole ecosystem, including mammals and seabirds. In the case of seabirds in the breeding season, displacement of a food resource due disturbance caused by the noise of human activities could have very considerable consequences for colonies<sup>110</sup>. Knowledge of marine mammals remains incomplete, notably concerning their distribution, daily movements and reaction to various acoustic activities. In addition, understanding the effects of human activities on these animals (birds and marine mammals) needs to involve exhaustive analysis of cumulated impacts, taking into account strikes with vessels, bycatch, contaminants and waste and, in the case of offshore wind farms, traffic disturbance linked to maintenance boats and tourism<sup>111</sup>. Future impact studies carried out by project leaders should prioritise the acquisition of new data and therefore the development of finer models for understanding impacts<sup>112</sup>.



Harbour Seals © Paul Bonfils

106. Kastelein *et al.*, 2006.  
 107. Gordon & Northridge, 2002.  
 108. Lopez *et al.*, 2011.  
 109. Dähne *et al.*, 2017.

110. CNRS, 2023.  
 111. Fontaine *et al.*, 2025  
 112. Virgili & Ridoux, 2021.

# RESEARCH AVENUES FOR REDUCING FLYING FAUNA MORTALITIES



## CIRCUMSTANTIAL LIGHTING, AN AVENUE FOR REDUCING BAT MORTALITY AND DISTURBANCE



Bats suffer from strike mortality, the risk of which can be accentuated by attraction behaviours toward wind turbines<sup>113</sup>, and the loss of habitat use caused by avoidance behaviours<sup>114</sup>. The reasons for these behaviours remain little-known, with only the wake effect<sup>115</sup>, high density of insects close to turbines<sup>116</sup> and resemblance of wind turbines to large trees<sup>117</sup> having been identified as possible mechanisms for explaining these phenomena. Consequently, there are still very few effective measures for reducing the impacts of wind power on the use of habitats by bats. Curtailment is widely practised, but it leads to sometimes quite heavy production losses for wind farm operators; its implementation could perhaps be optimised if the sources of bats' attraction toward wind turbines were better understood and mitigated.

Acoustic monitoring of bat activity was carried out in Germany around wind turbines fitted with conventional lighting, blinking continuously all night, wind turbines fitted with an ADLS (Aircraft Detection Lighting System) whose lights function on average 12% of the night, and on control sites without wind farms and with comparable landscape characteristics<sup>118</sup>. This study provides the first empirical proof that warning lights can be a major attraction factor for bats close to wind turbines. Setting up "circumstantial" lighting such as ADLS could therefore contribute to mitigating the impacts of wind turbines on bats without greatly affecting energy production.

These promising results should be completed by studies carried out at different times of the year because bats' behaviours regarding wind turbines seem to vary between the seasons<sup>119</sup>, and on wind farms set up in different landscapes and habitats<sup>120</sup>. Moreover, this acoustic monitoring was carried out at ground height and outside the period of maximum mortality<sup>121</sup>; a study at nacelle height or with mortality monitoring performed in late summer could validate the potential of ADLS for reducing the mortalities.

While, in France, the warning lights of wind turbines are highly regulated and must be certified as compliant by the civil aviation technical service, circumstantial lighting such as ADLS could be beneficial not only for bats, but also other animal species affected by strikes, such as insects and birds. In addition, it requires no modification to existing wind turbines and several certified systems are already available.

Finally, the reduction of artificial lighting at night generated by wind farms could improve their acceptability for local residents. Circumstantial lighting could therefore be deployed in combination with other existing reduction measures.

113. Richardson *et al.*, 2021.  
114. Barré *et al.*, 2018 ; Gaultier *et al.*, 2023.  
115. Leroux *et al.*, 2024.  
116. Voigt, 2021.  
117. Cryan, 2008.

118. Rapport Chiro-Eolum, Leroux *et al.*, 2024.  
119. McKay *et al.*, 2024.  
120. Solillo *et al.*, 2024.  
121. Rydell *et al.*, 2010.

# RESEARCH AVENUES FOR REDUCING FLYING FAUNA MORTALITIES

## COLOURING WIND TURBINES COULD IMPROVE THEIR DETECTABILITY BY BIRDS

In France, the regulations stipulate that all constituent elements of wind turbines need to be uniformly painted white. Yet vulnerability to strike risk could be closely linked to the visual perception of wind turbines by birds<sup>122</sup>, which on average discern contrasts much less than humans<sup>123</sup>.

To enhance the visibility of wind turbines and therefore reduce mortality risks, researchers have proposed applying paint of a contrasting colour to the machines. In Norway, on the 68-turbine wind farm of Smøla, black paint applied to the base of ten turbines led to a significant drop of 48% in Willow Ptarmigan strikes on these machines<sup>124</sup>. On the same wind farm, another project studied the efficacy of painting one blade black on four machines, obtaining a reduction of approximately 70% in bird mortalities (notably White-tailed Eagle) compared to other wind turbines<sup>125</sup>.

A later study on the Eemshaven wind farm in the Netherlands was carried out on a sample of fourteen wind turbines half of which with black paint on one blade. Over two years of weekly mortality monitoring, 436 corpses belonging to 81 species were found at the foot of wind turbines, without painting the blades seeming to have a significant statistically effect<sup>126</sup>. In parallel, an experiment in South Africa on four wind turbines painted with red bands on the blades showed a significant drop in raptor mortality, which accounted for 30% of the strikes recorded<sup>127</sup>.

The efficacy of colouring one or more blades to enhance the contrast of wind turbines therefore seems to depend on numerous factors such as the species present, the environment of the wind turbines, their contrast with the landscape and any surrounding infrastructure and the colour and pattern applied to the blades. The turbines' rotation speed can also influence their detectability by birds, certain species perceiving wind turbines as stationary at low rotation speeds (around 3 rev/min) which can stop them comprehending the danger<sup>128</sup>.

Painting one or more blades in contrasting colours therefore remains an interesting avenue of research for reducing the strike risk for avifauna by improving the detectability of wind turbines, provided the regulations regarding aerial obstacles are relaxed. Nevertheless, further experimentation needs to be carried out to better understand the conditions when this measure is effective.

122. Gémard *et al.*, 2024.

123. Blary *et al.*, 2024.

124. Stokke *et al.*, 2020.

125. May *et al.*, 2020.

126. Klop *et al.*, 2025.

127. Simmons, 2025.

128. Blary *et al.*, 2023.

## RECOMMENDATIONS

### INVEST IN ENERGY SOBRIETY AND THE EFFICACY OF PRACTICES

▀ Prior to setting up new renewable energy projects, ensure that the evolution of our energy needs is based on energy sobriety and efficacy, at both collective and individual scale, in order to consume less and better.

### PRIORITISE BETTER PLANNING AND AVOIDING IMPACTS

▀ Plan the development of onshore and offshore wind power outside the protected areas listed in the National Protected Areas Strategy (SNAP) 2030, and in compliance with the recommendations of the IUCN.

▀ Forbid the setting up of wind farms in high-biodiversity-issue sites, in particular a terrestrial or marine Natural Area of Ecological, Fauna and Flora Interest (ZNIEFF).

▀ Forbid the setting up of wind power projects inside the home ranges or migration corridors of species that are threatened or protected and/or covered by a National Action Plan. It is also recommended that particular attention be paid to natural habitats adjacent to protected areas and ecological corridors.

▀ Take into account the cumulated impacts of wind farms on biodiversity (wind turbines and also associated developments such as access routes, technical platforms, connection pathways) and other present or projected infrastructure right from the planning stage in order to implement the avoidance for sensitive areas. The cumulation of impacts needs to be taken into consideration for France but also neighbouring countries when species' migration routes are concerned.

▀ Prioritise avoidance measures in the planning and design of wind farms with regard to conservation issues (habitats and species) rather than reduction or compensation measures, whose efficacy is less clearly established.

### IMPROVE SCIENTIFIC KNOWLEDGE AND DEPLOYMENT OF TECHNIQUES FOR REDUCING THE IMPACTS OF WIND FARMS

▀ Develop knowledge about species and their behaviours, movements, interactions with wind turbines and mortality risk factors in order to seek the most effective avoidance and reduction measures.

▀ Continue research on the impacts of wind farms on all ecosystems where they are set up, notably to better characterise the effects of habitat loss, for example linked to wake or barrier effects, especially in areas where several wind farms are set up.

▀ Continue research on the role and functioning of sound perception in marine animal species, including invertebrates, so as to develop more effective underwater noise abatement systems for the works phase of offshore wind farms.

▀ Particularly focus research efforts on the marine environment, where scientific knowledge remains extremely fragmented, to better understand the issues and effects of wind farms and associated infrastructure.

▀ Continue research into the efficacy of reduction measures in wind farms, in particular high-potential or widely used measures: minimum distance from woodland margins and sensitive habitats, ground or water clearance distances in function of the behaviour of species present, stoppage of turbines by means of predictive and dynamic curtailment to limit strikes, adaptation of warning lights to reduce attractiveness, colouring wind turbines to improve their detectability, etc.

▀ Support the technological and methodological development of strike detection systems (thermal and diurnal cameras, sensors, etc.) that offer interesting prospects.

▀ Support work on detection-reaction systems (ADSs) to assist the wind power sector, upskill the State services and define clear performance requirements.

## RECOMMENDATIONS

### PROMOTE SHARING, TRANSPARENCY AND STAKEHOLDER INVOLVEMENT AT VARIOUS SCALES

- ▶ **Extend the principle of “biodiversity funds”**, introduced by the APER law, dedicated to funding nature restoration projects, national observatories and research on mitigating the impacts of all renewable energy facilities.
- ▶ **For exploratory measures whose efficacy has been experimentally proven** (circumstantial lighting, colouring wind turbines, etc.), **dialogue** with the parties concerned to relax the regulations and be able to generalise the measures.
- ▶ **Improve the rigour and precision of the mortality monitoring protocol** for onshore wind farms and generalise the use of a single real mortality estimation tool such as GenEst (internationally recognised as the most robust) on all French onshore wind farms.
- ▶ **Improve accessibility to all data from impact studies and monitoring**, and structure them according to FAIR (Findable, Accessible, Interoperable, Reusable) principles. This will ensure homogenous and coherent data management, and automate analysis such as calculating mortality estimations, thus simplifying the work of consultancies and researchers.
- ▶ **Finalise the updating of the DEPOBIO platform** to enable the recording of metadata and therefore complete banking of the data required for research works about the impacts of wind farms on biodiversity.

### CONSIDER THE REDUCTION OF IMPACTS AS A COMBINATION OF MEASURES AND A MULTI-BARRIER APPROACH

- ▶ **Include the risks affecting** all the species and habitats concerned by each wind farm project in order to implement several complementary avoid and reduce measures in both the works and operating phases.
- ▶ **Consider dynamic curtailment** as a complement to predictive curtailment because the latter does not detect small and medium-sized birds or migrating bats on time, although they are highly affected by wind turbines.
- ▶ **Anticipate all potential sources of disturbance** during the operating phase, especially, for offshore wind farms, the sometimes-considerable impacts on birds and marine fauna of maintenance boat and tourist visit traffic, which are not subject to the same legal obligations as wind power operators.

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