CHAPTER 6

OFFSHORE WIND TURBINE CURTAILMENT STRATEGIES IN NORTH SEA COUNTRIES TO REDUCE BIRD COLLISIONS

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Abstract

The Southern North Sea is part of one of the main migration flyways in Europe. The highest flight intensities at sea are recorded at night during spring and autumn migration and are mostly migrating passerines. These songbirds migrate at high altitudes, up to several kilometres but a portion of these birds flies at rotor height and is thus at risk of collision. Temporarily stopping the turbine operation during high collision risk events for songbirds, such as adverse weather conditions during migration bringing large numbers of passerines into the range of turbine rotors, may prevent a large number of collision victims. However, curtailing turbines at sea to reduce the collision risk is not yet being applied on a large scale. To support the ongoing discussions on this topic, this report aims to present an overview of curtailment strategies in wind farms at sea in North Sea countries. From the collected information it is clear that the Netherlands is pioneering in implementing curtailment measures in wind farms at sea, but also Germany and France are starting to perform tests. Other countries are open for discussions on the topic. Although temporary turbine shutdowns could be highly effective for reducing collision mortalities in certain scenarios, there is still a need for sound, site-specific monitoring programs to assess the effectiveness and to finetune the implemented measures. A regional approach to the implementation of curtailment strategies, could maximise the efficiency and ecological benefits of such policy measures. It is important to note that wind turbine curtailment is only one aspect to mitigate the impact of wind farms on bird populations. Responsible development further entails proper site selection, pre-construction environmental assessments, and post-construction monitoring.

1. Introduction

Birds and bats are directly affected by wind turbines through the risk of collision with structures (Drewitt & Langston 2006; Fox *et al*. 2006; Voigt *et al*. 2015; Thaxter *et al*. 2017). This conflict between renewable energy production and nature conservation is referred to as a 'green-green' dilemma (Voigt *et al*. 2019). To minimize the collision risk for birds and bats it is important to use optimal siting strategies for wind farms, for example by avoiding sensitive habitats (Marques *et al.* 2014; Harwood & Perrow 2019) or migratory pathways. Additionally, regulating the operation of wind turbines can further mitigate collision mortality for birds and bats (Cook *et al.* 2011; May 2017). This implies that the operation of some or all wind turbines of a wind farm is intentionally reduced or stopped during specific times when the risk of collisions is high. The reduced rotor speed increases the visibility of the turbine blades, and it reduces the probability of a bird or a bat flying through the rotor swept zone of being hit by a blade (Harwood & Perrow 2019).

One way to do this is 'shutdown on demand'. This means that a turbine or some turbines in a wind farm are stopped when the collision risk is high, e.g., when a bird is flying close to the rotor swept zone of a turbine (Marques *et al.* 2014). This has been successfully applied in wind farms located at bottlenecks for migratory soaring birds like some raptor species, storks, cranes, etc. (Smallwood & Karas 2009; de Lucas *et al.* 2012; Tomé *et al.* 2017a, 2017b). In most cases, the shutdown is initiated by human observers, with or without technological aids like radar, cameras, etc.

Secondly, turbine operations can be restricted in a wind farm as a whole, during massive migration events or during certain weather conditions when the collision risk is high (Marques *et al.* 2014). In this overview, this approach is further referred to as curtailment. Such general curtailment measure is often applied to reduce bat fatalities by increasing the cut-in wind speed (defined as the lowest wind speed at which turbines generate power) to those critical wind speeds at which bats reduce their activity (Arnett *et al.* 2010; Adams *et al.* 2021; Behr *et al.* 2018). Arnett *et al.* (2010) showed that reducing turbine operation during periods of low wind speeds reduced bat mortality with 44% to 93% and marginal annual power loss (< 1% of total annual output). For birds, restricting wind farm operation could be implemented when there is an identified, anticipated high collision risk. For example, wind farms on migratory routes could be shut down at nights of poor weather conditions to reduce the collision risk for nocturnally migrating birds (Marques *et al.* 2014).

Also at sea, significant collision risks exist for local and migrating seabirds and migrating terrestrial birds. The Belgian part of the North Sea (BPNS) is part of one of the main European migration flyways. Because of its shape, the Southern North Sea acts as a migration bottleneck, concentrating seabirds during migration. An estimated number of no less than 1.0 to 1.3 million seabirds migrate through this area on an annual basis (Stienen *et al.* 2007). Also, large numbers of non-seabirds are known to migrate at sea (Buurma 1987; Alerstam 1990; Lensink *et al*. 2002; Bradarić *et al.* 2020; Manola *et al.* 2020). Estimates of the number of birds seasonally travelling through the Southern North Sea vary from 85 million (Lensink *et al.* 2002) up to several hundreds of millions (estimates of Helgoland mentioned in Hüppop *et al.* 2006), of which the vast majority are terrestrial birds (Bradarić *et al.* 2020). While migratory ducks, geese and waders are restricted to coastal areas, songbirds migrate along a broad front across the North Sea (Vanermen *et al.* 2006). The highest flight intensities are recorded at night during spring and autumn migration and mainly consist of migrating passerines, especially Blackbird *Turdus merula*, Song Thrush *Turdus philomelos*, Redwing *Turdus iliacus* and Robin *Erithacus rubecula* (Krijgsveld *et al.* 2011; Fijn *et al.* 2015). Aside from barrier effects, the development of offshore wind farms (OWFs) in the North Sea might also directly impact these migrating birds through the risk of collision with the turbines, which results in an increased mortality rate.

Songbirds, migrate at altitudes up to several kilometres (Lensink *et al.* 2002; Krijgsveld *et al*. 2011; Brabant *et al*. 2021). According to the radar study by Krijgsveld *et al*. (2011) in the Dutch OWF OWEZ, an average of 330,000 (groups) birds/km crossed the wind farm zone between sea level and 1,385 m altitude (the maximum height of the radar image) each autumn, over 30% of these birds flew at rotor height. The flight altitude is, however, influenced by weather conditions. A general phenomenon is that birds fly at higher altitude with tailwind and that they fly at a lower altitude with headwind (Buurma 1987; Lensink *et al.* 2002).

Peaks of intense songbird migration in the North Sea occur during good weather with favourable, supporting wind conditions (Bradarić *et al*. 2020). Weather conditions can, however, change en route and therefore, crossing the North Sea basin is a risk for terrestrial birds as they cannot rest and refuel if weather conditions become adverse (Bradarić *et al.* 2020; Manola *et al.* 2020). When weather conditions deteriorate, birds will lower their flight altitude which results in large numbers flying at rotor height and thus at risk of collision. Lensink *et al.* (1999) reported three of these "falls" in the period from 1978 until 1990, but concluded, based on limited data at sea, that these events must occur yearly in the Southern North Sea. Fijn *et al.* (2015) also reported regular occurrence of intense bird migration at rotor height in the Dutch part of the North Sea.

At the research platform FINO 1 in the German Bight, a total of 767 dead birds were found during 160 visits between October 2003 and December 2007, distributed over 45 visits and 34 species (Hüppop *et al*. 2016). The most commonly found species were thrushes (76%), followed by starlings (9%) and other songbirds (10%). Collision was the main cause of death (75%) and more than half of the casualties occurred on only three autumn nights. The majority of these casualties occurred during very specific and difficult to predict conditions, characterized by favourable conditions in the areas of departure and rapidly deteriorating weather conditions over the sea during the following night, such as increasing cloudiness, fog, rain and changing wind conditions (Hüppop *et al*. 2006, 2016).

Temporarily stopping the turbine operation during such high collision risk events for songbirds can reduce the number of collision victims. However, curtailing turbines at sea to reduce the collision risk for birds is not yet being applied on a large scale. On 13 May 2023, the wind turbines at the Dutch offshore wind farms Borssele and Egmond aan Zee were stopped for four hours, during a massive songbird migration event (https://www.offshorewind.biz/2023/05/17/dutch-stop-offshore-wind-turbines-to-protect-migratory-birds-in-international-first/). This was an international first for wind farms at sea and was part of a pilot phase of the implementation of such procedure in the Netherlands. To support the ongoing discussions on this topic, this report aims (1) to present an overview of curtailment strategies and procedures to reduce bird collisions in wind farms at sea in North Sea countries and (2) to assess the possibilities to implement such mitigation measure in Belgian OWFs.

2. Methods

To collect information about current or planned curtailment measures in North Sea countries, governmental agencies, research institutes and wind farm developers from the Netherlands, Germany, Denmark, the United Kingdom, France, Norway and Belgium were contacted (Table 1). We inquired if there were any curtailment measures imposed on current and/or planned wind farms at sea or, if this was not the case, whether it is being actively discussed for potential future implementation.

3. Results

3.1. The Netherlands

As mentioned in the introduction, the wind turbines at the Dutch offshore wind farms Borssele and Egmond aan Zee were stopped for four hours, during a massive bird migration event on 13 May 2023 as a test. The rotation speed of the wind turbines was reduced to a

Table 1. List of persons that were contacted to gather information on the application of curtailment in wind farms at sea.

Name	Country	Organisation
Jos de Visser	The Netherlands	Rijkswaterstaat Zee en Delta
Karen Krijgsveld	The Netherlands	Wageningen Environmental Research
Marie Dahmen	Germany	Bundesamt für Seeschifffahrt und Hydrographie (BSH) - Federal Maritime and Hydrographic Agency
Benedikt Holtmann	Germany	Bundesamt für Seeschifffahrt und Hydrographie (BSH) - Federal Maritime and Hydrographic Agency
Freerk Nanninga	Germany	Skyborn Renewables offshore solutions GmbH
Helmut Wendeln	Germany	IBL Umweltplanung GmbH
Søren Keller	Denmark	Danish Energy Agency
Alex Banks	United Kingdom	Natural England
Julie Black	United Kingdom	Joint Nature Conservation Committee (JNCC)
Yann Planque	France	France energies marines
Etienne Berille	France	EDF Renouvelables
Emma Gouze	France	EDF Renouvelables
Roel May	Norway	Norwegian Institute for Nature Research
Steven Vandenborre	Belgium	Federal Public Service Health, Food chain safety and Environment

maximum of two rotations per minute during the predicted night-time peak migration to reduce the collision risk. Egmond aan Zee is the Netherlands' first offshore wind farm, consisting of 36 wind turbines located 10 to 18 kilometres off the Dutch coast. The two wind farms in Borssele are located at more than 20 kilometres off the coast of the province of Zeeland and comprise 94 and 77 wind turbines.

The shutdown of the wind farms Egmond aan Zee and Borssele during bird migration, was an international first for wind farms at sea and was part of a pilot phase. The goal of the Dutch government is to make this the standard for all operational and future wind farms (Table 2). Rijkswaterstaat is implementing a curtailment procedure for offshore windfarms in the Dutch part of the North Sea on behalf of the Ministry of Economic Affairs and Climate Policy (Van Bemmelen *et al.* 2022). The reasoning of the Dutch government to install a stand-still procedure is based on the Nature Protection Act, which prohibits intentional killing of birds. Article 3.1 of the Nature Protection Act states that it is prohibited to deliberately kill or capture birds naturally living in the wild in the Netherlands of species referred to in Article 1 of the Birds Directive. In addition to that, the duty of care under the Nature Protection Act also requires that 'damage to all wild animals and plants has to be prevented as far as reasonably practicable'. The competent authority has ruled that the ban on killing birds applies to offshore wind farms in the Netherlands, but that considering the implementation of mitigation measures to reduce bird collisions, an exemption can be granted.

The shutdown procedure relies on a bird migration prediction model, developed by the University of Amsterdam (Bradarić *et al.* in prep.). The model is based on bird migration data from a bird radar installed at sea and meteorological data. It predicts bird migration intensity up to 48 hours in advance. If a certain threshold is exceeded, then the intention is to shut down the turbines. The application

Table 2. Summary of the curtailment measures to reduce the collision risk for migrating birds in offshore wind farms in North Sea countries.

Country	Curtailment implemented in the North Sea	Curtailment in other sea basins	Status of implementation	Criteria to start curtailment
The Netherlands	**yes**	NA	Implementation in pilot phase. Procedure based on predictive bird migration model.	If predefined bird intensity threshold is exceeded, curtailment protocol is initiated.
Germany	no	**yes**	In OWFs in bird migration corridor in the Baltic Sea.	If predefined bird intensity threshold is exceeded.
United Kingdom	no	no	NA	NA
Denmark	no	no	NA	NA
France	no	**yes**	Curtailment implemented in an OWF test site in the Mediterranean.	Curtailment initiated during predefined periods in spring and autumn migration season.
Norway	no	no	NA	NA
Belgium	no	NA	NA	NA

of the standstill provision is concretized in a protocol in consultation with various stakeholders (https://www.noordzeeloket.nl/functies-gebruik/windenergie/start-stop/). Shutting down turbines based on real time bird radar is not possible because this would cause instability in the electricity network. Predicting the intense migration events well in advance with this model, allows grid operator TenneT enough time to maintain the stability of the high-voltage grid, and if necessary, purchase natural gas to guarantee the energy supply during the shutdown. As a validation of the model, a team of bird migration experts also provides a prediction of the bird migration intensity based on their expertise, on predicted weather conditions at the departure locations of migrating birds, next to observations of birds at migration counting sites. They then assess and compare with the prediction model outcome. The final decision to stop the wind farms at sea is with the ministry for Economic Affairs and Climate. This is then communicated to the wind farm operators with an indication of the date and time that turbines need to be stopped.

At this point, the prediction model is based on a limited dataset of bird radar data. The model will be improved by adding more bird radar data to train the model. In order to make the prediction model as accurate as possible and, in time, possibly differentiate between different wind energy areas in the North Sea, it will have to be based on multi-year data from bird radar systems on site. Wind farms will therefore be equipped with such bird radars at the expense of the Dutch government. This research can also reduce knowledge gaps on migratory bird species and thus contribute to future decision-making on offshore wind farms (RVO 2023a). This may also lead to a future adjustment of the shutdown threshold and a differentiation in the threshold value between regions in the North Sea.

The current model is developed for the wind energy areas along the Zeeland and Dutch Coast. Later, a separate model will be developed for the wind area North of the Wadden Islands, and the development of a third model is foreseen for the areas further offshore.

The condition to shut down the turbines during events of heavy bird migration is included in the 'parcel decision document' – a parcel is a designated area at sea where wind farms can be constructed. This condition states that the rotation speed of wind turbines needs to be reduced to less than two rotations per minute when the bird density exceeds a certain threshold.

Following on the parcel decision document, a tender is published and wind farm developers can prepare a bid to develop a project in that parcel. The bids are being scored based on criteria that are described in the tender document. In the latest tender, many non-price criteria are included (RVO 2023b). One of these is to develop a shutdown on demand measure which is a local curtailment strategy that partially shuts down the wind farm when target species are at risk of collision (e.g., little gull *Hydrocoloeus minutus*, northern gannet *Morus bassanus*, lesser black-backed gull *Larus fuscus*, black legged kittiwake *Rissa tridactyla*, greater black backed gull *Larus marinus*, herring gull *Larus argentatus*). This will be on top of the general shutdown procedure during heavy songbird migration, as described above.

3.2. Germany

There are curtailment measures for wind farms in the German part of the Baltic Sea but not (yet) for the German North Sea area. The Federal Maritime and Hydrographic Agency of Germany (BSH) is establishing a broad monitoring program on collision risk for the North Sea OWFs, which is described in the latest draft site development plan (BSH 2023a). Wind farm developers will need to develop a monitoring plan to continuously register bird flights in the wind farms. With that knowledge, a curtailment strategy will then be developed that might be applied in the future in the German part of the North Sea.

In the Baltic Sea, a curtailment procedure to reduce collision risk during mass bird migration events will be mandatory for all OWFs within a migration corridor that was described by the German Federal Agency for Nature Conservation (BfN) between the southern tip of Sweden and the coast of Mecklenburg-Western Pomerania (BfN 2020; Table 2). This has been identified as an area of particular importance for bird migration and should therefore be given special consideration in planning (BSH 2023b). In the environmental license of the latest OWF in the Baltic Sea, the Baltic Eagle project, there are specific conditions on bird migration monitoring and curtailment (BSH 2023b). For the first three years the wind farm developer needs to implement monitoring infrastructure consisting of a bird radar system and minimum five camera systems to continuously monitor the bird flux in the wind farm up to an altitude of 1000 m. If the estimated collision mortality is more than 1% of that total number of birds, the operation of the turbines needs to be stopped. The findings from the monitoring during the operational phase will be used to develop and implement site-specific mitigation measures considering varying collision risks at different weather conditions. The wind farm developer needs to propose a plan to BSH on how this curtailment procedure will be applied, but at this point (October 2023) no details are known. This same approach will be applied to all offshore wind farms that are in the Baltic bird migration route.

Aside from the general policy in German waters, there is a particular case where, as a result of a lawsuit by two environmental NGOs, turbine curtailment for nocturnal migration was implemented in the nearshore wind farm Nordergründe, in the inner part of the German Bight close to the Wadden Sea. The Nordergründe offshore wind farm consists of 18 turbines totalling 111 MW. It is located 17 kilometres off the coast of Lower Saxony and was Commissioned in 2017, in shallow coastal waters of the German Bight, in the vicinity of two nature conservation sites. It is 560 m away from the Site of Community Importance (SCI) and Special Protection Area (SPA) 'Nationalpark Niedersächsisches Wattenmeer' (DE 2306-301, DE 2210-401) and around 14 km away from the Site of Community Importance (SCI) 'Hamburgisches Wattenmeer' (DE 2016-301). Additionally, there are two areas of bird protection interest at ca. 1–5 km to the North and to the West of the project site, respectively named Roter Sand and Küstenmeer vor den Ostfriesischen Inseln.

Normally, the construction of an offshore wind farm would not be allowed there because of the possible negative effects on the nearby marine protected areas, but the Nordergründe site was exceptionally included in the spatial development plan as a testing location to gain experience before the development of offshore wind farms at a larger distance from the German coast. Two German NGOs, Bund für Umwelt und Naturschutz Deutschland (BUND) and WWF Germany, launched legal appeals against the project as they considered the permit a breach of nature conservation laws because of the related risks to birds. The project developer, in return, appealed against certain permit conditions. In March 2011, an agreement was concluded between the state of Lower Saxony, the project developer, and the two NGOs, BUND and WWF. The settlement defined a four-year research program to study the bird migration on site and the implementation of a stand-still procedure at the developer's expense. The latter obliged the project developer to stop the turbines during major bird migration events to reduce the collision risks for migrating birds. The stand-still procedure was implemented with the use of a vertical bird radar installed on site. During the migration periods the radar screen was monitored in real time each day for four hours starting at dusk. Radar echoes, assumed to be birds, where counted by the radar operator from sea level up to 300 m altitude on the radar images that were generated every three minutes. When a threshold of 20 radar echoes per radar image or 120 echoes in 20 minutes was exceeded, the turbines were shut down. In the settlement, it was agreed not to have more than 10 shutdowns per year and not to shut down when wind speeds were very high (>7 Bft, as bird migration was expected to be low) or very low (<3 Bft, as turbines are in idling mode). During five years the threshold was exceeded for 14 times. In 11 of those cases, the turbines were shut down. In the other three cases the wind speed was lower than 3 Bft and turbines were already in idling mode. After five years, the state ministry of the environment of Lower Saxony decided that the procedure could be stopped since the results gained from the research program on bird migration (Hill *et al.* 2022) did not provide evidence for a need to continue the obligation to shut down the turbines.

3.3. Denmark

Denmark has no curtailment procedures in place in existing offshore windfarms. The Danish Energy agency is confident that the wind farms have been located outside of important bird migration routes during the planning phase, and that, therefore, there is no reason for curtailment strategies.

In 2026, the wind farm "Aflandshage" will be constructed near "Øresund", in the Baltic Sea. At that site a curtailment procedure will probably be implemented due to the collision risk for bats.

3.4. United Kingdom

The contacted persons at Natural England and JNCC confirm that at this moment no curtailment measures are applied anywhere in UK waters, and that there are no plans to implement curtailment in the near future. Although it is not being actively discussed at this point, it should also not be ruled out as a future measure being put in place in UK waters and it may be something that is discussed/considered more in the future.

3.5. France

The development of offshore wind farms in France recently started. The first wind farm in French waters, at Saint-Nazaire, was commissioned in 2022. Other projects are currently under construction. A curtailment procedure is not included in the environmental measures of the first French OWF. However, this type of procedure is increasingly being discussed in the context of future wind farms in France, although these discussions are still at an early stage.

In the test wind farm Provence grand large (PGL) in the French Mediterranean, consisting of three floating turbines that will be commissioned in the first quarter of 2024, a curtailment measure will be implemented during the spring and autumn migration periods (Table 2). In April, the turbines need to be stopped during six consecutive nights, starting one hour before sunset. In September, this will be the case during seven consecutive nights. This measure is imposed by the environmental permit of the project and these periods were chosen based on a bird radar study at the coastline, during which the highest fluxes were detected in April and September. In 2024, a bird radar will be installed on the platform of one of the turbines and the aim is to improve the curtailment measure based on insights from that study.

3.6. Norway

Only last year, a first offshore wind farm, consisting of 11 floating turbines, was installed in Norwegian waters. A research programme to study bird migration in the area, including the use of weather radar data, a bird radar on site and citizen science has recently been financed. However, mitigating measures such as curtailment are not implemented yet.

3.7. Belgium

In Belgium, a first round of wind farms is constructed and fully operational since 2020. A second area for wind farm development – the Princess Elisabeth Zone (PEZ) – has been designated in the marine spatial plan (Chapter 1). Applications for environmental permits for wind farms in the PEZ have recently been submitted and are now subject to a licensing procedure. Conditions "to avoid, prevent or limit and, if possible, compensate significant adverse effects on the environment" (art.21 §2 – Law for the Protection of the Marine Environment and for the Organization of Marine Spatial Planning in the Belgian maritime areas December 11, 2022) can be imposed in the environmental permit. Stand-still procedures to reduce the collision risk are not implemented in the environmental permits of the first round of Belgian offshore wind farms. However, the legislation foresees an option to change or add conditions to existing environmental permits, if there is a necessity to do so. Up until now, this has not been the case. But, from a juridical perspective there is a possibility to implement a curtailment procedure for existing and future wind farms.

4. Discussion

From this assessment, it is clear that in the different North Sea countries, the Netherlands is pioneering with the implementation of the curtailment measures in wind farms at sea, but also Germany and France are initiating tests with curtailment. The Netherlands have developed an approach based on a predictive bird migration model that allows all stakeholders (e.g., wind farm operators, grid operators) to prepare for a planned shutdown of the turbines when a high collision risk is expected. By gradually improving the bird migration model and developing it for different areas within the Dutch part of the North Sea, it will be possible to apply this approach on all wind farms at sea in the Netherlands. Other countries are also taking steps towards the implementation of some form of curtailment strategies or are open for discussions on the topic.

To ensure the effectiveness of such measures, it is essential to correctly assess events with a high risk of collisions. This is crucial not only for minimizing energy production losses but also for maximizing the prevention of collisions.

The earlier statements by for example Cook *et al.* 2011 and Marques *et al.* 2014 regarding the effectiveness of curtailment measures are confirmed by recent studies. A study by Klop & Brenninkmeijer (2020) in the Eemshaven wind warm on land shows that applying a standstill measure during nocturnal migration peaks is an effective measure to prevent collision victims. Not a single collision victim was found underneath

10 turbines which were shut down for 10 nights of relatively intensive bird migration, while the number of victims found beneath the operating turbines was nearly three times higher than the average found on all other nights. Bradarić *et al*. (2023) claim that in the Dutch North Sea, curtailments should be performed during only 18 hours in spring and 26 in autumn, to minimize collision risk for 50% of birds migrating through the area. This represent 2.5% and 5.5% of the migration period, respectively and in that case, the yearly amount of energy lost due to curtailments would be 0.05% in spring and 0.07% in autumn. Hill *et al*. (2022) assessed the effectiveness of the shutdowns of the Nordergründe wind farm in the German Baltic Sea by calculating how many additional collisions continued operation of the wind turbines on the shutdown nights could theoretically have led to. They concluded that the number of collisions per year would have increased only insignificantly if no shutdowns had been carried out and the wind farm had continued to operate on the shutdown nights.

This demonstrates the need for sound, site-specific monitoring programs to assess the effectiveness of the implemented measures and to further finetune them. As such, the science-base to validate that shutting down turbines during events of mass migration actually prevents collisions of birds will be enlarged. One of the most important knowledge gaps remains the direct measurements of bird collisions at offshore wind facilities (Potiek *et al.* 2022). Such monitoring programs are being developed in several North Sea countries, e.g., Germany (BSH 2023a) and the Netherlands (RVO 2023a). These will gain valuable insights into the patterns of bird migration behaviour at sea and contribute to the development of more targeted mitigation and conservation strategies.

As curtailment measures can result in significant power generation reductions, wind farm operators are a key stakeholder for the effective implementation of curtailment strategies. To anticipate on the possible obligation to implement curtailment measures in the future, more and more industry parties are also investing in tools and technologies to improve curtailment strategies for birds and bats. For example, Ørsted recently invested in a “deep-tech” start-up that is developing an artificial intelligence system to monitor and track birdlife at offshore wind farms. The Vestas Bat Protection System (VBPS) is a newly developed software module intended to incorporate additional weather variables into curtailment decisions and increase power generation while maintaining conservation benefits (Whitby *et al.* 2023).

With the rapid growth in the number of wind farms in the North Sea, it is extremely important that this is done in the most ecologically responsible way possible. One of the conclusions of a stakeholder involvement process done by Voigt *et al.* (2019) was that concerns about bird collisions and other environmental impacts are common among stakeholders, including local communities, environmental organizations, and policymakers, and that proactive measures are necessary to make wind energy production ecologically sustainable. Temporary turbine shutdowns could be highly effective for reducing collision mortalities during certain scenarios, such as poor weather conditions during migration, bringing large numbers of passerines into the range of turbine rotors (Harwood & Perrow 2019). It is however important to note that wind turbine curtailment is just one aspect of a comprehensive approach to mitigate the impact of wind farms on bird populations. Responsible development further entails proper site selection, pre-construction environmental assessments, and post-construction monitoring. A regional approach to the implementation of curtailment strategies, including all possible stakeholders, could maximise the efficiency and ecological benefits of such policy measures.

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