CHAPTER 6

TURBINE SIZE IMPACTS THE NUMBER OF SEABIRD COLLISIONS PER INSTALLED MEGAWATT AND OFFERS POSSIBILITIES FOR MITIGATION

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Abstract

As the offshore wind energy technology is rapidly progressing and because wind turbines at sea have a relatively short life span, repowering scenarios are already being discussed for the oldest wind farms. Ongoing developments result in larger wind turbines and an increased open airspace between turbines. Despite taller towers having larger rotor swept zones and therefore a higher collision risk area compared to smaller-sized turbines, there is increasing evidence that fewer but larger, more power-efficient turbines may have a lower collision rate per installed megawatt. As such, turbine size can offer an opportunity to mitigate seabird fatalities by increasing the clearance below the lower rotor tip.

We assessed the seabird collision risk for a hypothetical repowering scenario of the first offshore wind farm zone in Belgian waters with larger turbines and the effect of an additional increase in hub height on that theoretical collision risk.

For all species included in this exercise, the estimated collision risk decreased in a repowering scenario with 15 MW turbines (40.4% reduction on average) because of higher clearance between the lower tip of the turbine rotor and the sea level, and the need for a lower number of turbines per km². Increasing the hub height of those 15 MW turbines with 10 m, further decreases the expected number of seabird collisions with another 37% on average.

However, terrestrial birds and bats also migrate at sea and the effect of larger turbines on these taxa is less clear. Possibly even more terrestrial birds and bats are at risk of collision compared to the current turbines. So, while larger turbines and increasing the hub height can be beneficial for seabirds, this likely needs to be applied in combination with curtailment strategies, which stop the turbines

during heavy migration events, to reduce the impact on other species groups.

1. Introduction

At present, 399 wind turbines, with capacities ranging between 3.3 and 9.5 MW, are operational in an area designated for renewable energy in Belgian waters. This totals an installed capacity of 2.26 GW (chapter 1 of this report). The first turbines were constructed in 2008 and the last ones in 2020. As the offshore wind energy technology is rapidly progressing and because wind turbines have a relatively short life span of ca 20-25 years (Bonou *et al*. 2016), repowering scenarios are already being considered. A second zone for offshore renewable energy in Belgian waters, the princess Elisabeth zone, was designated in the revised marine spatial plan in 2020 and is anticipating an installed capacity ranging between 3.15 and 3.5 GW. These developments reduce our dependence of fossil fuels but on the other hand can pose negative effects on birds. Birds are affected directly through collision with structures, and indirectly through behavioural responses to the altered habitat (Drewitt & Langston 2006; Fox *et al*. 2006). To estimate the direct seabird mortality caused by collisions with offshore wind turbines, avian collision risk models (CRM) are used. These models integrate a variety of bird and turbine parameters to calculate the theoretical collision risk. The model outputs should be handled with care and not be interpreted as absolute figures considering the uncertainty around specific input parameters. They are however very useful to compare development scenarios and to identify the species most at risk (Brabant *et al.* 2020). CRMs are therefore routinely used in environmental impact assessments and the outputs may have actual consequences for wind farm developments, weighing on consenting decisions (Masden *et al.* 2021).

The developments in wind energy technology result in increasingly large wind turbines, with several types already exceeding a capacity of 10 MW (De Kooning *et al.* 2021). Currently, the largest turbines on the market are the 14 MW Siemens Gamesa 14-222 DD, the 14 MW GE Renewable Energy's Haliade X and the 10 MW Vestas V164. In February 2021, Vestas announced a new 15 MW V236 offshore turbine to be available by 2022, thus pushing the size of wind turbines even further with a rotor diameter of 236 m. The V236-15.0 MW was selected for the He Dreiht offshore wind farm (900 MW) in the German North Sea in 2025 (De Kooning *et al.* 2021).

Larger turbines have higher rotor planes and an increased open airspace between neighbouring turbines. Despite taller towers having larger rotor swept zones and therefore a higher collision risk area compared to smaller sized turbine, there is increasing evidence that fewer but larger, more power-efficient turbines have a lower collision rate per megawatt (Marques *et al.* 2014; Shimada 2021). This technological evolution towards larger turbines can thus have a positive side-effect as they may result in fewer seabird collisions.

Turbine size also offers the opportunity to mitigate seabird fatalities (Arnett & May 2016), as increasing the draught height of turbines, i.e., the height between the water surface and the lower tip of the rotor, by 5 or 10 meter can be applied as a measure to reduce collision risk. In the UK this measure is being tested in three OWFs (Hornsea 2, East Anglia 3 and Vanguard; MacArthur Green 2019) and is recommended by Natural England for all future projects in the North Sea. It is also being considered in the Netherlands (personal comment Witteveen & Bos).

The aim of this report is to assess the seabird collision risk for a hypothetical repowering scenario of the first offshore wind farm zone in Belgian waters with larger turbines and to simulate the effect of an increased draught height on that theoretical collision risk.

2. Material and methods

2.1. Research strategy

The first offshore wind farm zone in Belgian waters has a surface of 238 km². The area is fully occupied by nine operational wind farms with a total installed capacity of 2.26 GW, resulting in an average capacity of 9.5 MW/km². New developments and repowering scenarios, however, are aiming to increase the capacity per km². In the second zone for renewable energy, the Princess Elisabeth zone (PEZ), the aim is an installed capacity ranging between 3.15 and 3.5GW, which would accord to 11.1 and 12.3 MW/km² respectively and an average turbine capacity between 15 and 17 MW. Repowering the first zone to 11.7 MW/km², the average of the goal for the PEZ, would imply 181 turbines of 15 MW and an installed capacity of 2.71 GW.

In this study we calculated the collision risk of six seabird species for (1) the current operational wind farms in the first zone for renewable energy in Belgian waters, (2) a repowering scenario of that first zone with 15 MW turbines with a standard height and (3) a repowering scenario with 15 MW turbines with a 10 m increased turbine hub height.

2.2. Collision risk modelling

Estimating bird collisions at sea is routinely done using theoretical CRMs, which calculate species-specific collision risks based on wind farm and turbine specifications, bird-related parameters and bird densities (Masden & Cook 2016). The CRM most frequently used is the one developed by Band (2012). The Band model (Band 2012) has undergone several modifications over the years and now provides four different options for calculating collision risk. Option 3 of the extended model uses species-specific flight height distributions from Johnston *et al.* (2014), in contrast to the basic model that assumes a uniform distribution of flight height between the lowest and the highest level of the rotor swept area. Masden (2015) developed a CRM, based on the Band model, that includes uncertainty and variability of the input variables. The Masden (2015) model was further improved by McGregor *et al.* (2018) to develop a stochastic version of the Band (2012) CRM, providing a more robust and transparent method of accounting for uncertainty in the estimation of seabird collision rates, also including the four model options developed by Band.

The stochastic CRM (sCRM) is available in two ways: as an online Shiny application (https://dmpstats.shinyapps.io/avian_stochcrm/) and as an R package that can be downloaded and run locally (https://github.com/dmpstats/stochCRM). We calculated the collision risk with the model option 3 of the sCRM in the online application. Option 3 of the model is considered the most realistic calculation (McGregor *et al.* 2018). The input parameters needed for the sCRM are further described in the paragraphs below.

The sCRM was run for 3000 iterations for the three different scenarios, resulting in species-specific numbers (±standard deviation) of collision victims per year.

2.3. Turbine related input data

For the second scenario with next generation wind turbines at sea, we used the specifications of the Vestas v236 15 MW turbine prototype. This turbine has a rotor diameter of 236 m, while the hub height is site specific (Vestas website). The height of offshore turbines is determined by the height of the transition piece (TP) which is determined by the wave regime in the area. On top of the transition piece, a safety clearance is needed so the lowest tip of the rotor can move freely above the TP platform, crane, etc. In Belgian waters the TP height would be around 20 m above the lowest astronomical tide (LAT). Adding 10 to 15 m clearance above the TP and the radius of the rotor (118 m), results in a hub height of about 150 m LAT for this Vestas v236 15 MW turbine (pers. comm. Belgian windfarm developer Parkwind).

Table 1. Wind farm and turbine related input data for the stochastic CRM for the currently operational wind farms and both repowering scenarios in the first renewable energy zone in Belgian waters.

	N of turbines	Width (km)	Latitude (°)	Tidal offset (m)**	Turbine model (MW)	Number of blades	Rotor radius (m)	Air gap*** (m)	Max blade width (m)	Rotor speed (rpm)	Pitch (°)
Norther*	44	4.3	51.52	4.3	8.4	3	82	21	5.4	10.95	5.2
C-Power	54	4.4	51.55	4.3	6.15	3	63	27	5	12.22	5.6
Rentel	42	4.7	51.59	4.3	7.35	3	77	24.5	5	11.62	5.4
Northwind	72	3.1	51.62	4.3	3.3	3	56	23	4	14.85	6
Seastar	30	2.8	51.64	4.3	8.4	3	83.5	21.5	5.4	10.95	5.2
(No)Belwind	106	5.1	51.67	4.3	3.3	3	56	23	4	14.85	6
Northwester II	23	4.2	51.69	4.3	9.5	3	82	20.4	5.4	10.52	5.1
Mermaid	28	3.6	51.71	4.3	8.4	3	83.5	21.4	5.4	10.95	5.2
Repowering scenario	181	35	51.62	2.0	15	3	118	28.0	7.8	10.52	5.1
Repowering scenario +10m	181	35	51.62	2.0	15	3	118	38.0	7.8	10.52	5.1

*scenario 1 is the sum of the collisions calculated for the nine wind farms currently installed. The Nobelwind OWF is built around the Belwind OWF and therefore Belwind and Nobelwind are considered as one project. Belwind and Nobelwind have different turbines (Vestas V90 and Vestas V112 respectively). We used the Nobelwind turbine dimensions as a worst-case scenario.

**tidal offset is the difference between mean sea-level (MSL) and highest astronomical tide (HAT).

***air gap is the distance between the lowest tip of the rotor and the sea-level measured as HAT (Masden *et al*. 2015).

The CRM was applied on the current OWFs in Belgian waters and on two repowering scenarios, the first one with the Vestas v236 15 MW turbine with a 150 m LAT hub height and the second one with an increased hub height of 160 m LAT.

The input data for the currently installed OWFs (scenario 'as is') and the two repowering scenarios are shown in Table 1. For the latter we considered the first OWF zone as one homogenous wind farm with Vestas v236 turbines (Table 1). As the Vestas v236 turbine is under development some parameters remain unknown because of non-disclosure agreements. Therefore, rotor speed and pitch were taken from Gyimesi *et al*. (2018) for the biggest turbine currently operational in Belgian waters, i.e., the Vestas v164 turbine. Blade width of the Vestas v236 is also unknown, so we extrapolated the blade width from the Vestas v164. Information on turbine activity per month were taken from Masden *et al*. (2015).

2.4. Species selection

The focus of this study was on the six most abundant seabird species inside the Belgian offshore wind farms: northern gannet *Morus bassanus*, common gull *Larus canus*, lesser black-backed gull *Larus fuscus*, herring gull *Larus argentatus*, great black-backed gull *Larus marinus* and black-legged kittiwake *Rissa tridactyla* (Vanermen *et al*. 2019). Other species were not selected because of insignificant post-construction densities inside the wind farms or because they are at low risk of collision because of their low flying height (e.g., razorbill *Alca torda*, common guillemot *Uria aalge*). Great cormorant *Phalacrocorax carbo* was not considered either, despite the fact that this species is frequently observed perching on the jacket turbine foundations in the C-Power wind farm on the Thorntonbank (Vanermen *et al*. 2019). Strangely, however, this species is rarely recorded flying inside the wind farm, resulting in negligible densities of flying birds.

Table 2. Bird related input data for the stochastic CRM.

Species	Northern gannet	Common gull	Lesser black-backed gull	Herring gull	Great black-backed gull	Black-legged kittiwake
Avoidance rate (%) [1]	99.9	99.8	99.8	99.9	99.6	99.8
SD Avoidance rate (%) [1]	0.03	0.07	0.06	0.05	0.11	0.06
Body_Length (m) [2]	0.94	0.41	0.58	0.6	0.71	0.39
SD Body_Length (m) [2]	–	–	0.03	–	–	0.005
Wingspan (m) [2]	1.725	1.11	1.43	1.44	1.58	1.08
SD Wingspan (m) [2]	–	–	0.0375	–	–	0.0625
Flight_Speed (m–s) [1]	13.33	9.8	10.13	9.68	9.78	8.71
SD Flight_Speed (m–s) [1]	4.24	3.63	3.93	3.47	3.65	3.16
Nocturnal_Activity (% of diurnal activity)	0.25 [3]	0.5 [3*]	0.43 [4]	0.01 [4]	0.5 [3]	0.5 [3]
Flight	Flapping	Flapping	Flapping	Flapping	Flapping	Flapping
Proportion Flight	1	1	1	1	1	1

[1] Skov *et al*. (2018), [2] Snow & Perrins (1998), [3] Garthe & Hüppop (2004, * common gull not mentioned, therefore we took the same value as for other gull species mentioned in this study); [4] Gyimesi *et al*. (2017).

2.5. Bird related input data

Avoidance rates and flight speed data are taken from the empirical study of Skov *et al*. (2018). Body length and wingspan are taken from Snow & Perrins (1998). Nocturnal activity data for lesser black-backed and herring gull are described by Gyimesi *et al*. (2017), based on telemetry data from birds in Dutch, Belgian and English colonies. For the other species the assumptions of Garthe & Hüppop (2004) are adopted. Flight type for seabirds is regarded as flapping, not gliding. Proportion in flight is set at 1, as the density data are based on flying birds only (Table 2).

2.6. Bird density data

Monthly post-construction bird surveys started in 2010 and 2013 on the Bligh Bank and Thorntonbank offshore wind farms respectively and were continued for five years. Details on the applied methodology and sampling scheme can be consulted in Vanermen *et al*. (2016, 2019). During these surveys flying birds and birds on the water were counted separately and we selected only the flying birds to calculate seasonal densities as input for the sCRM.

The post-construction density data of the Bligh Bank and Thorntonbank offshore wind farms were averaged and used to calculate the collision risk for the different scenarios of the first renewable energy zone (Table 3).

3. Results

For the current nine wind farms in the first Belgian zone for renewable energy (scenario 1) a total of 60.7 ± 236.4 collisions

Table 3. Average post-construction density data (mean n/km² ± SD) of flying individuals of six seabird species inside the wind farms on the Bligh Bank and the Thorntonbank in winter (December-February), spring (March-May), summer (June-August) and autumn (September-November).

Season	Northern gannet	Common gull	Lesser black-backed gull	Herring gull	Great black-backed gull	Black-legged kittiwake
Winter	0.00 ± 0.00	0.29 ± 0.50	0.03 ± 0.06	0.03 ± 0.11	0.07 ± 0.13	0.56 ± 0.61
Spring	0.01 ± 0.03	0.01 ± 0.02	0.25 ± 0.39	0.01 ± 0.04	0.01 ± 0.04	0.07 ± 0.17
Summer	0.01 ± 0.03	0.00 ± 0.00	0.18 ± 0.17	0.00 ± 0.00	0.03 ± 0.05	0.00 ± 0.00
Autumn	0.01 ± 0.04	0.02 ± 0.07	0.04 ± 0.10	0.01 ± 0.02	0.17 ± 0.25	0.12 ± 0.22

Table 4. sCRM option 3 output (3000 iterations) resulting in an estimated number of collisions per species per year (± SD) for the three different scenarios.

Species	Scenario 1: current OWFs (n collisions / year ± SD)	Scenario 2: repowering scenario (n collisions / year ± SD)	Scenario 3: repowering scenario +10 m (n collisions / year (± SD)
Northern gannet	0.2 ± 2.5	0.0 ± 0.02	0.0 ± 0.26
Common gull	6.9 ± 94.8	3.9 ± 62.5	1.5 ± 33.2
Lesser black-backed gull	16.9 ± 133.9	5.8 ± 142.0	4.9 ± 125.2
Herring gull	0.8 ± 24.8	0.5 ± 15.4	0.1 ± 5.8
Great black-backed gull	32.3 ± 202.8	25.7 ± 346.6	6.7 ± 105.9
Black-legged kittiwake	3.6 ± 26.6	0.3 ± 8.4	0.5 ± 11.9
Total	60.7 ± 263.4	36.2 ± 380.1	13.7 ± 167.8

per year are expected for the six selected seabird species (Table 4). Lesser black-backed and great black-backed gull have the highest risk of collision in the current OWFs and account for 81.5% of the total number of collisions. Only 0.7% of the total number of expected collisions are attributed to northern gannets. The total number of collisions per year decreases with 40.4% in a development scenario with 181 15 MW turbines (scenario 2). This reduced collision risk is species-specific and for the species with the highest collision risk the reduction varies between 20.4% for great black-backed gull, 43.5% for common gull and 65.7% for lesser black-backed gull. Increasing the hub height with 10 m (scenario 3) further decreases the expected number of collisions in the current OWFs with another 37% on average, relative to scenario 2.

Repowering the first zone for renewable energy in Belgian waters with 15 MW turbines reduces the number of collisions per MW installed capacity with an average of 50.4% for the six selected seabird species (Table 5). Increasing the hub height of these 15 MW turbines with 10 m results in 81.2% less collisions per MW compared to the current OWFs.

4. Discussion

Lesser and great black-backed gull have the highest risk of collision in the current OWFs. For the other four species the risk is limited which is explained by their lower densities inside the wind farms (Vanermen *et al*. 2019) and their lower flight altitude (Johnston *et al*. 2014).

For all species included in this exercise, the estimated collision risk decreases in a repowering scenario with 15 MW turbines (40.4% reduction on average). The observed reduction is a combination of higher clearance between the lower tip of the turbine rotor and the sea level, and the lower number of turbines per km². Seabird flight height profiles indicate that most birds at risk of collision are flying in the lower part of the swept area (Johnston *et al*. 2014). Thus, a higher clearance above

Table 5. Number of collisions of the six selected species per year per MW installed capacity for the three different scenarios.

	Installed capacity (MW)	Number of collisions / year ± SD	Number of collisions / (year*MW)
Current OWFs	2260	60.7 ± 263.4	0.027
Repowering scenario	2715	36.2 ± 380.1	0.013
Repowering scenario +10 m	2715	13.7 ± 167.8	0.005

the water surface can significantly reduce the number of birds exposed to collision risk. The average clearance of the current OWFs is 22.7 m HAT. For the 15 MW turbines considered in the repowering scenario this would be 28.0 m HAT. Also, because the capacity of the individual turbines is higher, less turbines are needed which further reduces the collision risk per megawatt. It is important to note that it is unclear how repowering scenarios with fewer but bigger turbines will affect the seabird densities inside the wind farms. We used the post-construction seabird densities observed in the current wind farms. The increased spacing between larger turbines might result in a reduced avoidance response of seabirds and thus higher densities, which in turn would increase the collision risk again. This trade-off needs to be considered on a case-by-case basis (Harwood & Perrow 2019). Possibly also the flight height distribution of seabirds might be altered in wind farms with increased spacing between turbines. Telemetry studies could provide valuable data on flight height distributions in wind farms with different configurations.

Davies & Band (2012) consider turbine height as a management tool for bird collision risk at offshore wind farms. As the flight height distribution of seabirds is skewed to relatively low height above the sea surface (Furness *et al*. 2013; Johnston *et al*. 2014), increasing the clearance of the rotor-swept area above sea-level is likely to reduce the risk of seabird collisions through a reduction of bird densities at risk height (Harwood & Perrow 2019). This is confirmed by the further reduction in collision risk through a 10 m increase of the hub height of the 15 MW turbines. This third scenario in our model calculations reduces the total number of collisions with 77.4% compared to the current OWFs, but also with 62.2% compared to the standard repowering scenario. The outcome of our model calculations are in line with the calculations of MacArthur Green (2019) which yielded a reduction in predicted collision risk of 41% on average, for an increase in turbine clearance of 5 m (from 22 to 27 m HAT) for the Norfolk Vanguard offshore wind farm. Increasing the turbine hub height can thus be an effective mitigation measure to reduce seabird collisions and should be considered in future developments and repowering scenarios, although this creates additional engineering and material costs.

Aside from seabirds, also several hundred million terrestrial birds of approximately 250 species migrate over the North Sea every year, many of them being nocturnal migrants (Lack 1963; Lensink *et al*. 1999; Hüppop *et al*. 2006) and are as such at risk of collision with offshore wind turbines (Hüppop *et al*. 2019). Especially Blackbird *Turdus merula*, Song Thrush *Turdus philomelos*, Redwing *Turdus iliacus* and Robin *Erithacus rubecula* migrate in high numbers across the North Sea at night (Krijgsveld *et al*. 2011; Fijn *et al*. 2015). During migration, birds fly at greater altitudes than when foraging or commuting between sites (Garthe & Hüppop 2004) and choose the altitude stratum in which their energy costs are lowest (Hüppop *et al*. 2006), ranging from sea level up to 10 km. Passerine migrants tend to fly relatively low in the atmosphere (< 1000 m) during most nights (Gauthreaux 1991), and their flight altitude is affected by wind and other atmospheric variables (Bruderer *et al*. 1995).

Bird radar data from a location inside one of the OWFs in Belgian waters demonstrate that large proportions of nocturnal migrants fly at rotor height (Brabant *et al*. 2021a). 44.3% of the radar recordings during autumn migration in 2019 were at rotor height of the current turbines (Brabant *et al*. 2021a). This figure would increase to 58.3 % for the Vestas v236 turbines that were used in the repowering scenarios in this study. As an example, on 29 October 2019 there was heavy nocturnal migration. The migration traffic rate (MTR) from 7 to 8 pm was 613 birdtracks per km per hour at rotor height. For the new Vestas v236 turbines this MTR at rotor height would have been 967 birdtracks per km per hour, as this type of turbine has a larger rotor pane. This means that more migrating songbirds will be at risk with bigger compared to smaller turbines. With this MTR, a scenario with 181 Vestas v236 turbines would result in 9% more collisions of songbirds than the current 399 wind turbines. So, the technological developments towards bigger turbines might benefit seabirds, but can result in more songbird collisions.

Bats are also known to migrate above the North Sea (Brabant *et al*. 2021b; Lagerveld *et al*. 2021). The flight height distribution of bats at sea remains unclear. It was thought that they generally fly at low altitudes, but bats were also detected acoustically at hub height in OWFs in Belgian waters (Brabant *et al*. 2019). The number of detections at nacelle height was around 10 % of the detections at low altitude (15m above sea level). Hatch *et al*. (2013) visually observed bats at higher altitudes at sea (>100 m). So, at least a part of the migrating bats are at risk of collision with offshore wind turbines. The behavioral response of bats to offshore turbines is also poorly understood and some studies indicate that bats are attracted to the turbines lighting (Voigt *et al*. 2018). It is therefore difficult at this point to predict how bats will be impacted by larger turbines. Taller turbines may even result in greater mortality for bats (Barclay *et al*. 2007). Curtailment strategies that idle turbines during intense migration events are therefore probably the most effective measure to mitigate the collision risk for migratory songbirds and bats (Cook *et al*. 2011; Marques *et al*. 2014; May 2017; Boonman 2018). To conclude, while larger turbines and increasing the hub height can be beneficial for seabirds, they likely need to be applied in combination with curtailment strategies to reduce the impact on other species groups.

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