AVES Wind Onshore anti-collision system

to protect the red kite (*Milvus milvus*)

Species protection assessment

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Table of contents

Tables:

Figures:

1. Introduction

In the light of anthropogenic climate change, renewable energies are a key pillar in the realisation of climate protection targets in Germany. The German government has set the course to become independent of fossil fuels. The environmentally friendly further development of renewable energies should cover 80 % of electricity consumption by 2030 (EEG 2023).

Wind energy use currently plays the leading role in the growth of renewable energies. In 2022, the installed capacity of wind turbines amounted to 66,242 megawatts (MW) spread over 29,982 turbines (Bundesverband Windenergie 2022). Of these, 28,443 turbines with an output of 58,106 MW were located on land and 1,539 turbines with an output of 8,136 MW were located at sea. The amount of electricity generated was 123.3 terawatt hours (TWh), corresponding to a 25.9 % share of German electricity production. In 2023, this could be increased to 140 TWh with a capacity of around 69,000 MW. By the end of 2030, 115,000 MW of onshore wind energy is expected to be installed.

1.1. Background and scope

Like all construction projects, wind turbines represent an intervention in nature and landscape. In planning, strict regulations apply, to particularly ensure the protection of nature and certain bird and bat species.

When approving wind turbines, it is therefore relevant to assess the provisions prohibiting killing and injury in accordance with Section 44(1) No. 1 BNatSchG. The significance approach developed by case law that was included in Section 44 (5) Sentence 2 No. 1 BNatSchG is used to assess whether the risk of killing or injuring the species concerned is significantly increased. A significant increase in risk means a considerable increase of the in a man-made landscape already existing risk to be killed. This significance approach, which has also been adopted by law, does not describe a statistical probability of collision, but is aimed at a decision that considers the nature conservation assessment and necessary avoidance measures in each individual case.

With the fourth amendment to the Federal Nature Conservation Act (BNatSchG) from 2022, specifications were made for the species conservation assessment of the prohibition of killing and injuring breeding birds at risk of collision. The habitat potential analysis (HPA) was introduced as a standard method to check whether there is a significant risk that a bird collides with a wind turbine. The HPA is a tool to predict the spatial use of birds based on the habitat characteristics of the site essentially at the desk. It replaces the time-consuming spatial use analysis (RNA), which involves multiple expert site inspections and extensive flight observations.

It is becoming increasingly difficult to find locations for wind turbines that do not conflict with species conservation legislation. Compliance with the prohibition of killing certain bird of prey and large bird species at risk of collision is of crucial importance in the approval procedure. In the vast majority of current project plans, there is an increased risk of killing.

To reduce the collision risk of wind energy-sensitive bird species, more and more anti-collision systems are being developed. These are systems able to detect certain target bird species, especially birds of prey, at the wind turbine site in real time and shut down operations when they enter the danger zone. By selectively switching off or slowing down the rotor speed to idle mode, the risk of colliding with the rotor blades shall be reduced below a significance threshold. However, the Federal Nature Conservation Act does not contain a specific definition of this significance threshold.

Section 45b of the Federal Nature Conservation Act (BNatSchG) mentions anti-collision systems as a possible protective measure that can be used to avoid or reduce the risk of birds colliding with wind turbines. They can be used as an alternative to blanket shutdowns where the effectiveness is usually based on empirical values. Aim is to combine species protection requirements for bird protection with minimised losses in electricity generation. Needs-based shutdowns considerably reduce the downtime of a system for reasons of species protection.

Whether the detection systems available on the market are sufficiently efficient and reliably reducing the collision risk to below a significance threshold has hardly been scientifically investigated to date. The present report aims to prove the effectiveness of the AVES Wind Onshore anti-collision system for the protection of the red kite based on the investigations carried out.

This validation report for the AVES Wind Onshore system analyses the implementation of the data collection and presents the statistical results in the context of the requirements under species protection legislation (MEKUN 2024, KNE 2021; BIONUM GMBH 2024).

1.2. Target species red kite

In Germany, the red kite is a very common bird of prey species. It mainly inhabits open landscapes scattered with small copses and forests and often prefers areas characterised by extensive boundaries between forest and open land and a high proportion of grassland. The red kite is a foraging hunter that systematically searches large areas of its feeding territory for prey in a relatively low and slow gliding and soaring flight. The species shows no avoidance behaviour towards wind turbines. As mating flights in spring, thermal soaring and some foraging flights take place at heights of rotors of the wind turbines, the species is prone to a very high risk of collision. Depending on the food availability, the birds often remain in Germany throughout the winter. Therefore, the risk of collision while foraging persists during these months.

The red kite is strictly protected by the Federal Nature Conservation Act. This protection in turn derives from the implementation of the EU Birds Directive. Wind energy projects therefore have to prove that the construction of the wind turbine does not increase the risk of collision and thus being killed for red kite. To ensure that the presence of a bird does not become an insurmountable obstacle to planning, the legislator has introduced the above described significance threshold. This means that wind energy plans only violate the Federal Nature Conservation Act and therefore cannot be implemented if the risk posed by the planned wind turbine is significantly higher than the general risk to the life of the species concerned.

Germany hosts around 60 per cent of the world's red kite population. This results in a particular responsibility – especially when with the expansion of wind energy adds a further risk to the human-related causes of death.

The State Bird Observatory & Field Centre Brandenburg keeps a register of birds that have died at wind turbines. This is not a systematic search for fatalities, but rather random finds. The database lists 750 red kite killed in Germany (as of 9 August 2023). The only species with a higher number of fatalities is the common buzzard with 771 birds killed and recorded in the database. The numbers of fatalities of both populations are similar. However, the population size of both species has to be taken into account. The population of the red kite is 14,000–16,000 breeding pairs in Germany. The population of the common buzzard is 68,000–115,000 breeding pairs (Ryslavy 2020).

Whether a wind turbine becomes a problem for a red kite depends on various factors. The location plays a major role. In summer, the German birds are primarily occupied with breeding, rearing their young and hunting. This leads to a high level of flight activity both in the near of the nest as well as between nest and hunting and feeding habitats.

The Federal Nature Conservation Act has redefined the distance rules between the nest of a red kite and the nearest wind turbine with close range (500 m), central range of verification (1,200 m) and extended test range (3,500 m). A wind turbine in the close range of a red kite nest means a significantly increased risk of killing and it is unlikely that a wind turbine will be approved at this site.

If the distance between breeding site and wind turbine is larger than the respective close range and smaller than the respective central area of verification, there are indications of an increased risk of killing (Section 45b (3) BNatSchG). The operator can use a habitat potential analysis to refute this presumption (Section 45b Section 45b (3) No 1 BNatSchG).

Sufficient risk mitigation for the species in question is generally already achieved if the approval authority specifies suitable technical protective measures in the approval, such as anti-collision systems, shutdowns during agricultural events, the creation of attractive alternative feeding habitats or species-specific shutdowns (Section 45b (3) No 2 BNatSchG).

If the distance between breeding site and wind turbine is larger than the respective close range and smaller than the respective extended area of verification, the risk of killing is not significantly increased (Section 45b (4) BNatSchG).

2. MEKUN Testing framework for anti-collision system

A number of basic requirements have to be met to ensure that an anti-collision system adequately protects birds at risk of collision near wind turbines. These requirements were established in the technical convention proposal for a testing framework for anti-collision systems (MEKUN 2024). The AVES Wind Onshore system was assessed in accordance with these requirements and criteria. The requirements are briefly explained below and the implementation is discussed.

2.1. Response area and detection area

No size is specified for reaction area and detection area. The response area is determined project-specific around the centre of the rotor of a wind turbine up to which a bird has to be detected and classified to ensure that the wind turbine is shut down on time. Height and radius of the cylinder (torus) depend on the wind turbine-specific dimensions as well as horizontal and vertical flight speeds. The detection area runs around the response area as a ring and is continued into the vertical axis. The outer radius of the detection area (torus) needs to be larger than the response radius and the inner radius needs to be smaller than or equal to the response radius (Figure 1). Three slightly different ring-shaped detection areas with a torus of 200 m width were investigated.

Its height is calculated in the same way as the height of the response area (rotor diameter plus a buffer depending on radius and flight speeds). The outer radius of the torus is used instead of the response radius. The resulting additional buffer in the vertical axis is necessary to ensure sufficient detection of all birds approaching the response area from above or below.

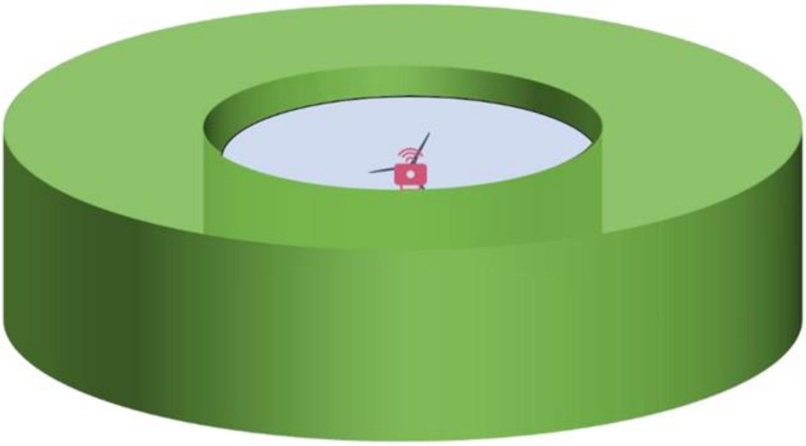

Figure 1: ring-shaped detection area (green) enclosing the response area (blue) (figure taken from MEKUN 2024).

AVES Wind Onshore is a multi-camera anti-collision system that specifically adapts the number of cameras to the project. In the present field tests to determine the rates and for validation, two to four cameras were always used per study area. The detection area was adapted to the respective field of vision.

In order to allow for application in as many scenarios as possible, an as large as possible detection area is chosen. Detection areas of different extents are included additionally to facilitate the assessment/transfer of the degree of protection to different project-specific response areas.

To determine the response area, the species- and wind turbine-specific response radius needs to be calculated. This radius (r_response) can be calculated based on four main values:

1. The average species-specific horizontal flight speed (v_bird),
2. the time that elapses between the system-induced switch-off signal and the wind turbine reaching idle mode (t_shutdown),
3. the average on-site relative measurement error of the anti-collision system (c_measurement error) and
4. a measure c_rotor blade, which is derived from the rotor radius.

The response radius is calculated as:

r_response = (v_bird· t_shutdown + c_rotor blade)·(1 + c_measurement error).

The following values were used for AVES Wind Onshore:

- v_bird = 8.54 m/s (see LfU testing framework for anti-collision systems for red kite (MEKUN 2024)).
- t_shutdown is a combination of two sub-components: the time latency t_latency, which measures the time interval between the system-induced switch-off signal and the moment the switch-

off signal arrives at the wind turbine in question (delays may occur here, for example, due to the prioritisation of signals in the context of wind farm control), as well as the time t_idle mode the turbine requires on average to switch from regular operation to idle mode. Both values are project-specific. Realistic values were determined for these two variables during validation, namely t_idle mode = 30 s and t_latency = 2 s.

- c_rotor blade: 0.637-times the rotor radius, i.e. 0.637*75 m
- c_measurement error: defines the average on-site relative measurement error of the anti-collision system.

Relative because the error naturally increases with the distance between the anti-collision system and the target. Therefore, the absolute error (e.g. given in metres) is divided by the respective distance between the anti-collision system or wind turbine and target to obtain the relative measurement error as a measure that is independent of the distance. For this purpose, BioConsult SH compared the red kite laser rangefinder points of five survey days to the positions determined by the anti-collision system. On average, the deviation was 20 % for red kite. The distance measurement was monocular. LRF points were only included in the statistics if the point was correctly detected and recognised by the anti-collision system. Overall 548 LRF points at different distances between the anti-collision system and target were analysed.

This results in a response radius of:

Red kite: $r\_response$ = 385 m.

The height of the response area is determined by the lower and upper rotor limits and an additional buffer. The buffer is determined from the assumed the change in altitude of the flying bird while it passes the response radius. The empirical measurements suggest that all investigated birds studied show vertical speeds of around 1 m/s while ascending or descending across all species (see testing framework for anti-collision systems MEKUN 2024). This means that the buffer (in units of metres) results directly from the quotient of the response radius and the horizontal flight speed. However, in order to take a particularly precautionary approach in this project, the investigated detection range is not limited upwards and downwards, but includes all LRF points that were located in the air column above the torus defined above. In this way, even birds flying from the ground or far above into the response area are represented in the determined rates.

2.2. Total rate

According to the technical convention proposal for a testing framework for anti-collision systems (MEKUN 2024), it needs to be ensured that the anti-collision system reliably identifies the respective bird species at risk of collision, here the red kite. Requirements apply to the total rate and a minimum value is required. The total rate is a combination of detection rate and identification rate. The requirement of a lower confidence interval ensures that the average rate is sufficiently high and can be determined with appropriate confidence. Therefore, the overall rate will with a certain probability be above a defined minimum value. The lower limit of the confidence interval for the overall rate was set at a minimum of 70 %. The total rate has to be achieved at a sufficiently large distance to ensure that the wind turbine is switched off in good time before the target species (in this case the red kite) enters the rotor area or the response area.

3. Data and method

3.1. Wind farm and survey area

The effectiveness of the AVES Wind Onshore anti-collision system was tested at two wind turbines at the Gnutz-Timmaspe wind farm in Schleswig-Holstein as well as at mobile sites in northern Germany. The descriptions of the system refers to the installations at the turbines in the Gnutz-Timmaspe wind farm.

Ten wind turbines belong to the wind farm located to the west of Neumünster. The two test turbines the most southerly of the wind farm and are approximately 200 m apart (Figure 2).

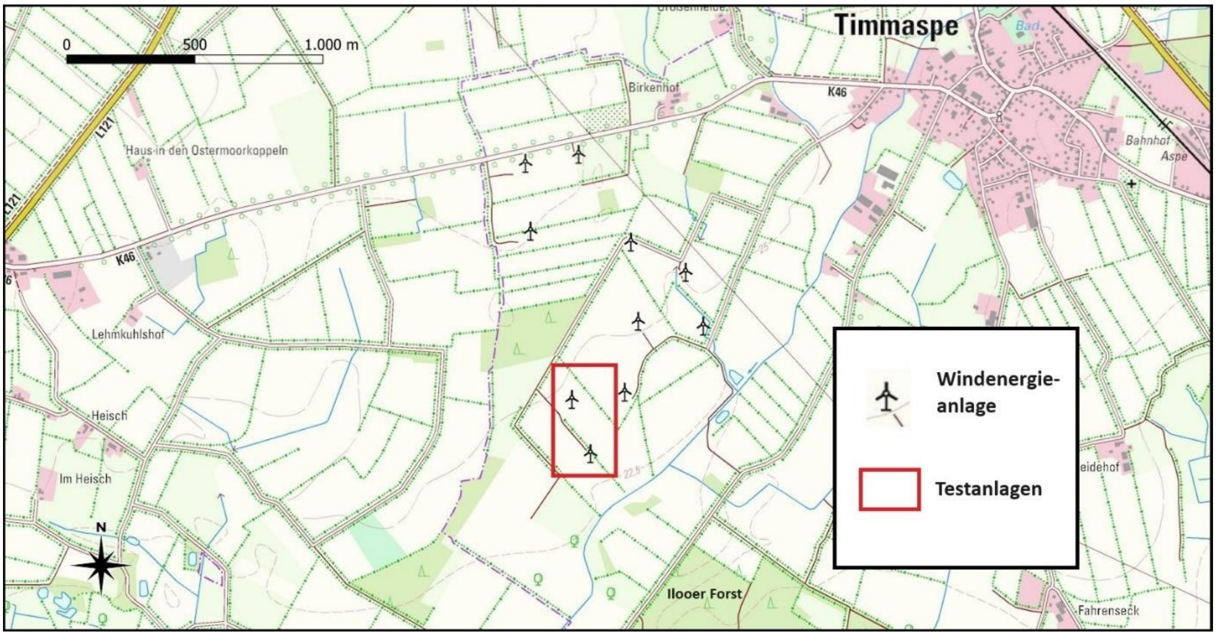

Figure 2: Location of the test wind turbines.

Five red kite nests are known near the wind farm. They are located in different directions, at distances of between 3,000 m and 5,000 m. A high probability of birds flying past in search of prey is to be expected due to the edge of the Iloo Forest only 500 m to the south of the wind farm. As already described in section 1.2, red kites like to hunt along boundaries between forest and open land and are therefore guided towards the test wind turbines.

The wind turbines that were equipped with the AVES Wind Onshore anti-collision system for the test belong to the N149 series manufactured by Nordex, Hamburg. Both wind turbines have a total height of 200 m, a rotor diameter of 149 m (i.e. the radius is 74.5 m) and a hub height of 125 m. They have a ground clearance of 51 m (Figure 3).

Figure 3: The two test wind turbines in the foreground and the edge of the picture on the right.

3.2. Camera system

The cameras used are industry-proven security cameras that monitor the airspace around the wind farm by panning, tilting and zooming. These are so-called pan-tilt-zoom cameras that can pan around two axes and zoom in on the image (Figure 4). The terms PAN and TILT are used in this context to describe the angles the cameras can be set to.

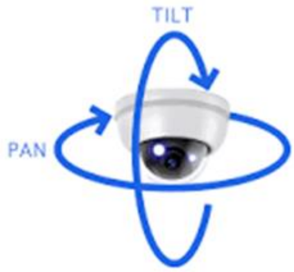

Figure 4: PAN/TILT operation of the cameras.

All cameras used are identical and installed in a weatherproof and shockproof housing (Figure 5). In addition to the lens, each camera has an infrared spotlight with a range of 400 m behind the second glass cover to support the night vision mode. The infrared light cone automatically adapts to the current zoom factor so that even illumination is guaranteed also at night. This means that the system can if required be extended to cover nocturnal species. An integrated windscreen wiper ensures a clear view in the event of adverse conditions such as precipitation, dirt or insects in front of the lens.

Figure 5: Camera system with infrared spotlight behind the second glass cover.

For the tests, the cameras of the AVES Wind Onshore anti-collision system were attached to the tower of the wind turbine at a height of 10 m. Two camera systems were installed at each of the two wind turbines for the test operation (Figure 6).

Figure 6: Camera systems at the tower of the Gnutz-Timmaspe wind turbine.

The camera has an initial angular aperture of 30° to observe an as large area as possible (Figure 7 and Figure 8). A zoom factor of 30 allows the target object to be magnified for correct species identification.

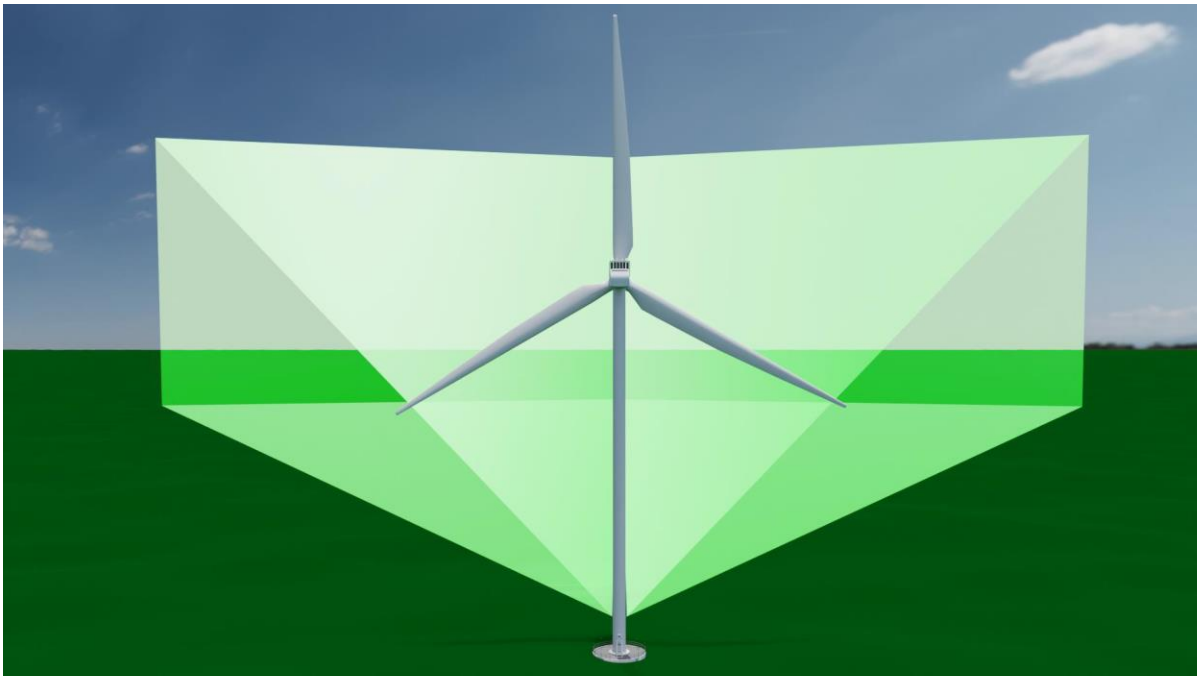

Figure 7: Vertical field of view.

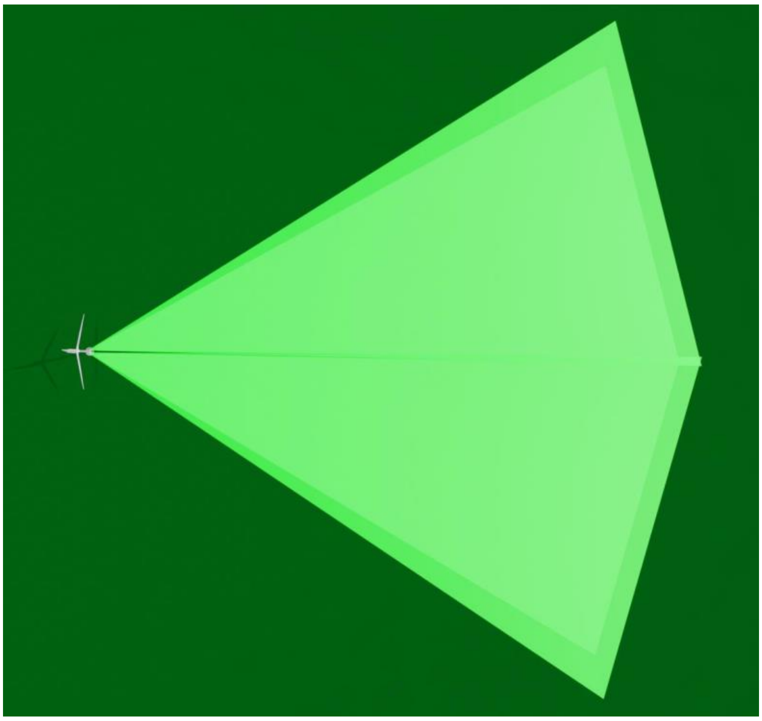

Figure 8: The two times 30° horizontal field of vision due to two cameras installed at one wind turbine.

4. AVES Wind Onshore mode of operation

Technical concept of the AVES Wind Onshore system is that several mobile cameras continuously monitor the entire airspace around the wind farm (principle of a protective wall, Figure 9**Fehler! Verweisquelle konnte nicht gefunden werden.**) and switch the affected wind turbines to idle mode as soon as the target bird species enters the project-specific response area.

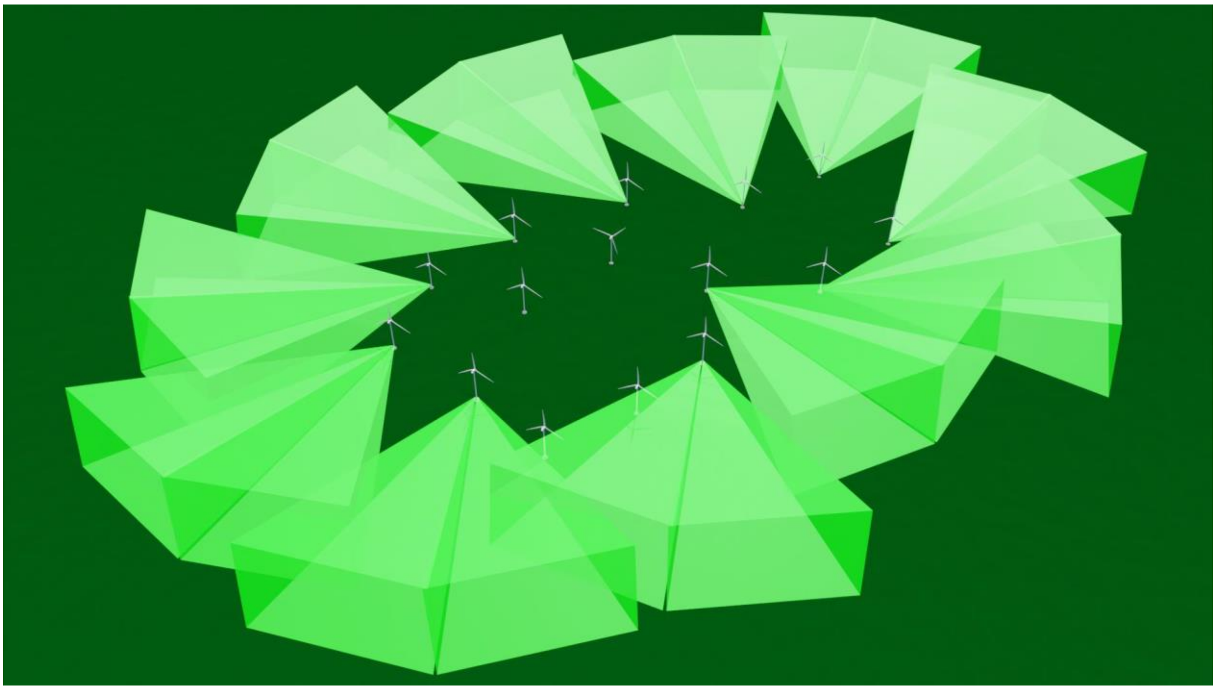

Figure 9: Monitoring the airspace around a wind farm.

4.1. Detection of the target species

If a flying object approaches and enters the monitored airspace of a camera, the object is automatically detected by the respective tracking software, tracked and zoomed in on for identification (Figure 10).

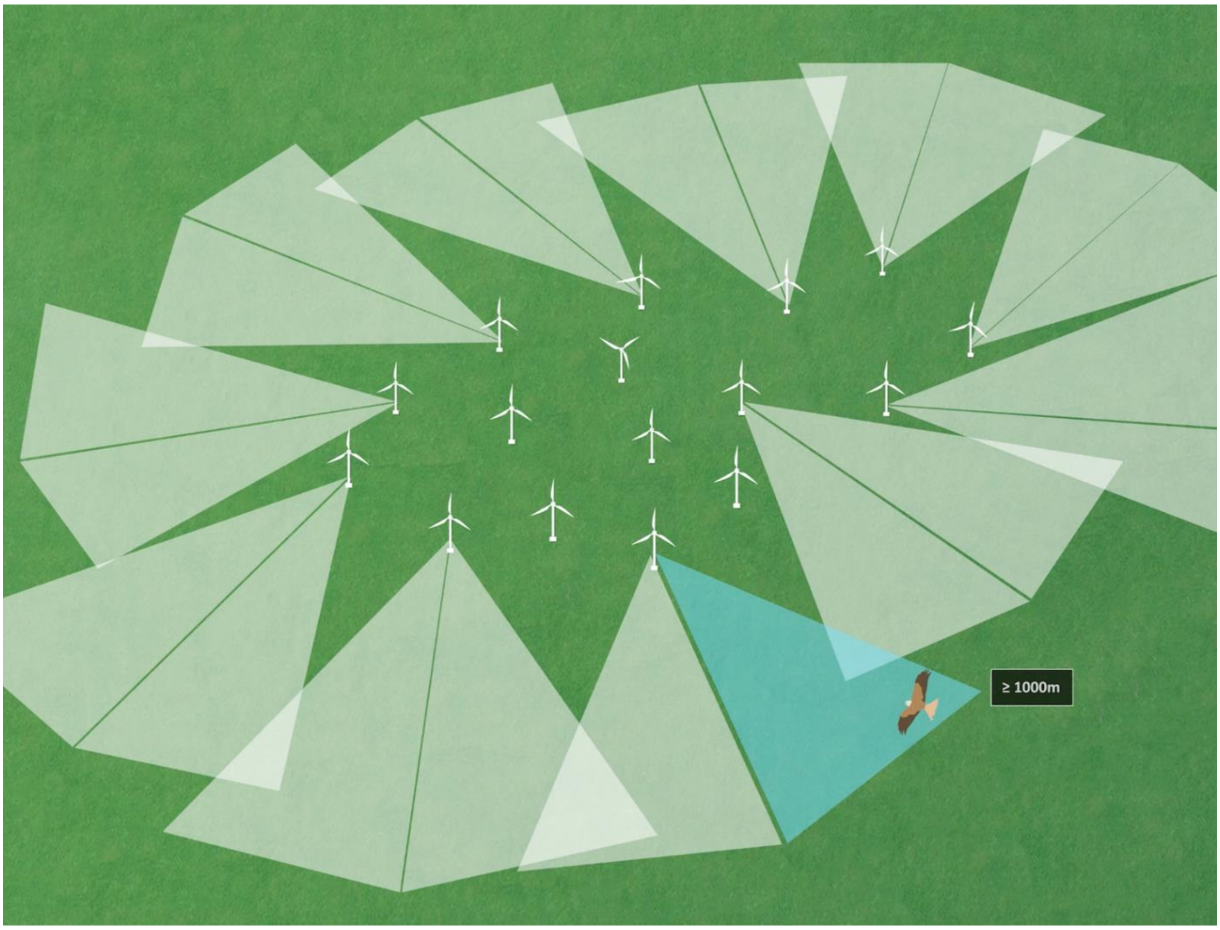

Figure 10: The target bird enters the field of view of the camera.

Depending on the size of the object and visibility conditions, the cameras can detect objects at distances of up to 1,000 m or more.

An AI specially tailored to the wind farm determines whether the object is the target bird species (Figure 11), another flying object or a bird species that is not associated with a switch-off specification (Figure 12).

Figure 11: Target bird species identified.

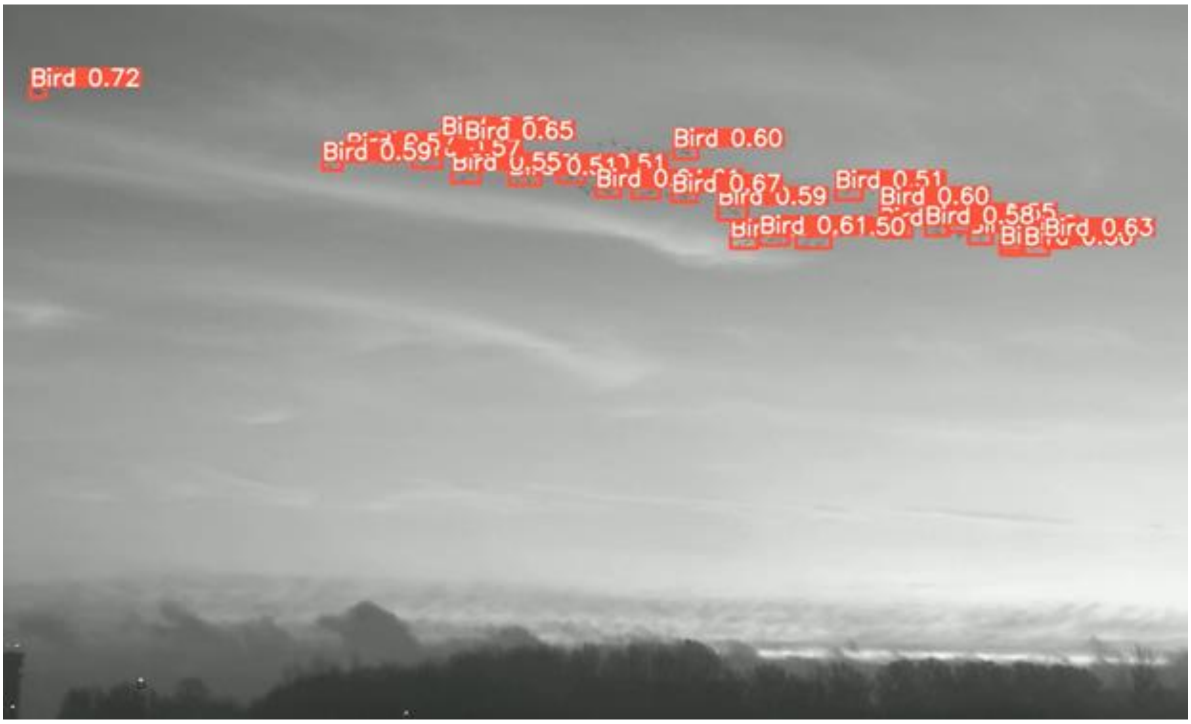

Figure 12: Flock of birds, no target species (nocturnal AI)

If a target bird species is detected, its flight path can be tracked exactly. Attaching the cameras to the side of the wind turbines also enables tracking into the wind farm. For this purpose, the target bird is captured by at least two cameras that are further apart and an exact three-dimensional position is determined via the intersection of the two camera images (Figure 13). Based on the size in the image as well as the flight pattern, it is determined whether a bird is likely to be an individual of the target species even before it is identified. The camera then pans and zooms in on the bird to determine its exact species.

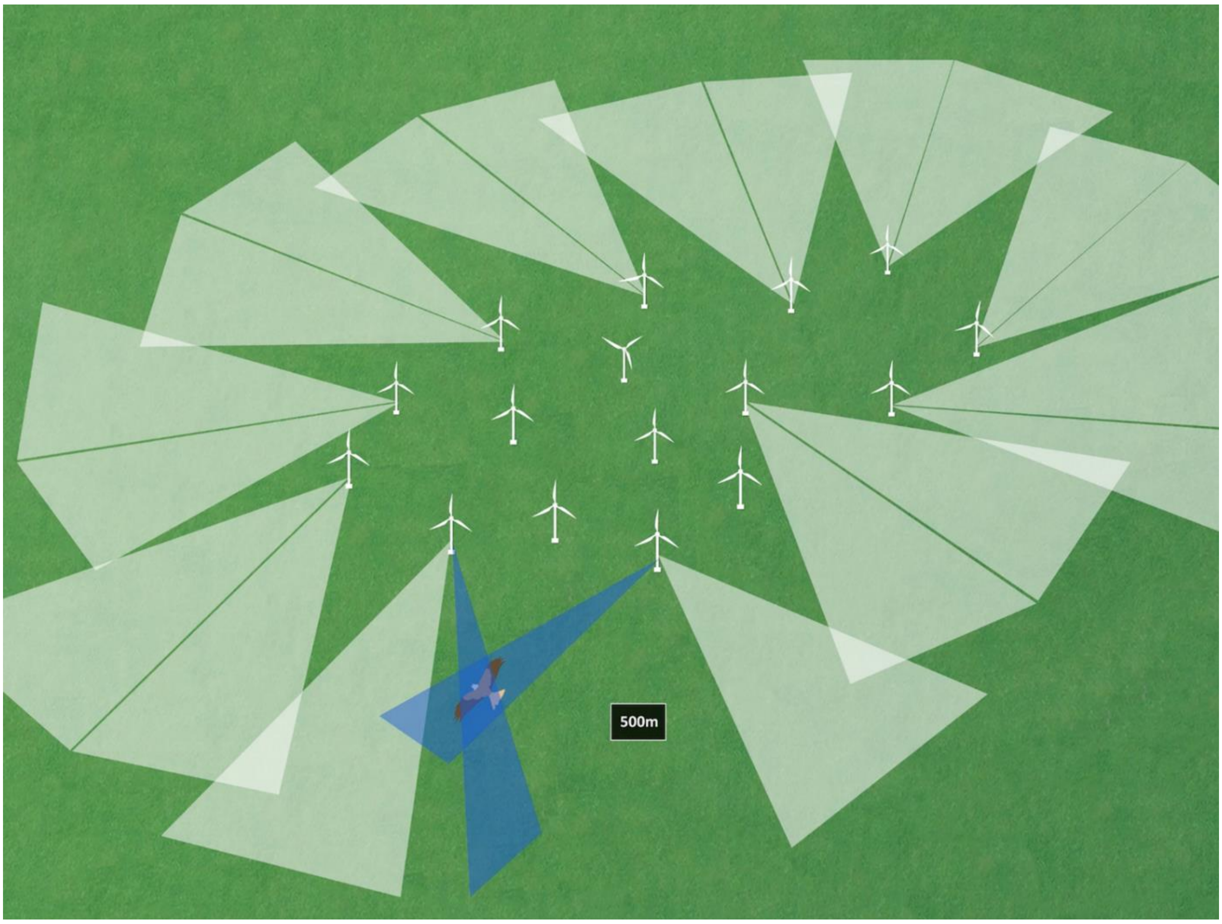

Figure 13: Two cameras track the targeted bird.

4.2. Initiating idle mode

Determining the position allows specifying when the target bird comes too close to at least one wind turbine so that the respective wind turbine is switched to idle mode (Figure 14) and when it has left the danger zone again so that operation can be resumed.

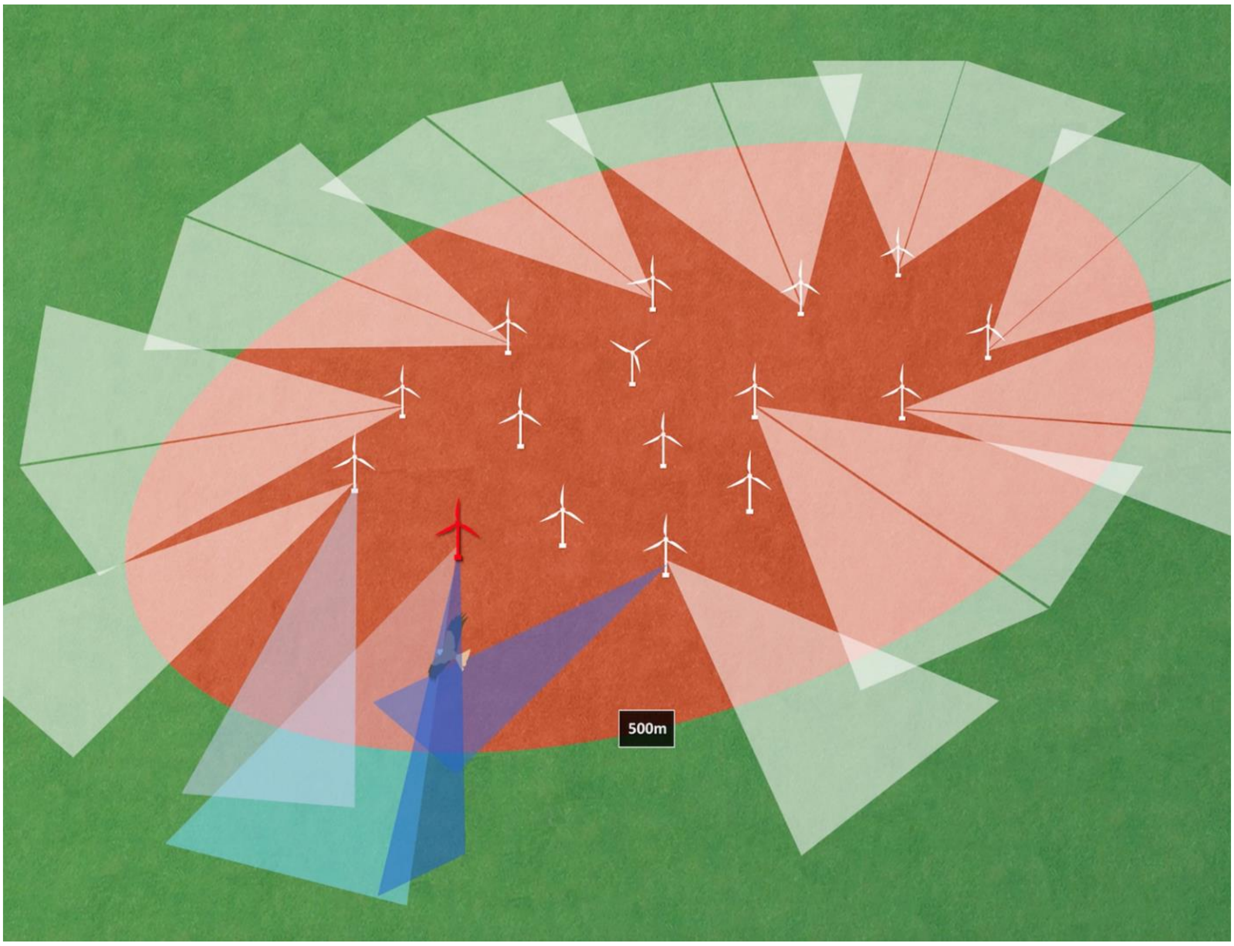

Figure 14: Switching the affected wind turbine to idle mode.

In idle mode, the rotor blades are turned out of the wind but the wind tracking of the rotor nacelle is still active. The speed of the rotor blades is the decisive factor. Blade tip speeds which do not significantly increase the risk to be killed (e.g. 25 or 30 km per hour) have not been defined. The tips of the rotor blades of the Nordex 149 turbines travel 468 m at one revolution per minute and reach a speed of approx. 28 km/h in idle mode. Depending on the wind speed, the rotor of a 2 MW turbine that is turned into the wind rotates 10–20 times per minute.

Other than a maintenance run for lubrication, idle mode is no operation in terms of the BNatSchG.

As soon as a camera no longer has to track its current target because it is not the target species or a target bird has left the danger area (Figure 15) it zooms out again to 30° aperture angle and the camera swivels back to its initial position so that it has a complete view of its sector again. Each camera can then detect up to 256 birds simultaneously.

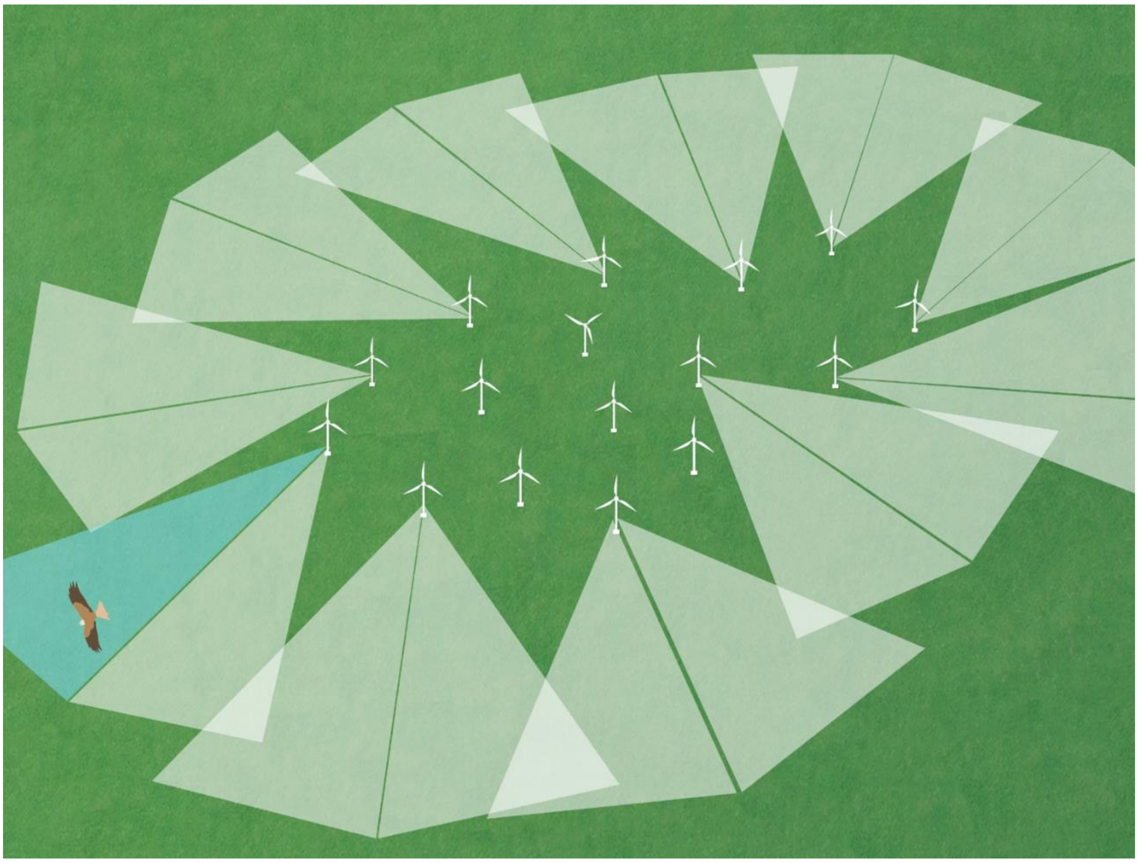

Figure 15: The target leaves the danger zone.

The AVES system can be remotely maintained and event logs can be saved and retrieved via a connection to the wind farm's IT infrastructure. A web front end is provided for this purpose, which can be accessed both from the wind farm's intranet and from the internet.

Several camera systems distributed throughout the wind farm, which are attached to the wind turbines, ensure seamless monitoring.

5. Field tests

5.1. Direct ornithological observations

To show that the AVES Wind Onshore system can minimise the collision risk for the red kite in particular, parallel observations by an ornithologist were compared to the recordings of the cameras of the anti-collision system.

At least one Bioplan ornithologist from used a laser rangefinder (LRF) to observe all birds flying past in the defined field of vision of the cameras. The position of the observer or observers was chosen so that the area around the wind turbines or wind farm was clearly visible. At least the target species-specific response area and the entire detection area of the system to be tested had to be seen, to determine the detection range.

The Vector 21 Aero model by Vectronix was used as the LRF (Figure 16).

Figure 16: The Vectronix 21 Aero laser rangefinder.

Technical data of the LRF Vectronix Vector 21 Aero:

- 42 mm binoculars with 7x magnification, adjustable eye relief, distance measurement 5 m to 12,000 m.
- Use of a class 1 laser (DIN EN 60825-1: the accessible laser radiation is non-hazardous or the laser is in a closed housing).
- Dimensions: 205 mm x 178 mm x 82 mm, weight: 1.7 kg.
- Powered by a 6 V lithium battery or external power source from 7 VDC to 14 VDC.
- Bluetooth or RS-232 interface to PC, smartphone, tablet or Garmin GPS series 60/72/76.

With the help of the LRF, the azimuth, the slant distance and the vertical angle of the measured target object were recorded using a laser beam (Figure 17).

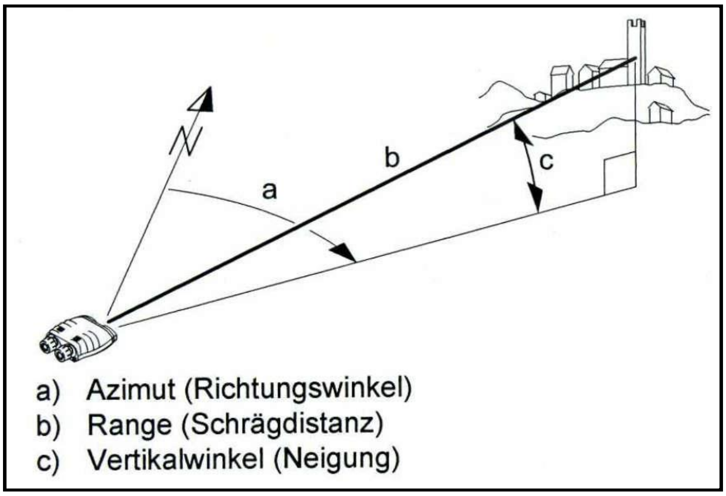

Figure 17: Operation of the LRF Vector 21 Aero.

LRF samples, which were recorded approximately every 5 to 10 seconds, were collected on 25 survey days between 4 August and 14 September 2023 at five different locations in parallel to the AVES Wind Onshore system. Only the survey days with red kite sequences were included in the analysis. On four days, there was no red kite activity in the area of the cameras (see Table 1).

Table 1: Overview of survey locations and days.

Number	Date	Location	Number of red kite sequences
1	03.08.2023	Trappenkamp	0
2	04.08.2023	WP Timmapse	9
3	05.08.2023	WP Timmapse	12
4	06.08.2023	WP Timmapse	21
5	07.08.2023	WP Timmapse	19
6	07.08.2023	Groß Buchwald 3	9
7	08.08.2023	WP Timmapse	0
8	08.08.2023	Groß Buchwald 3	5
9	09.08.2023	Groß Buchwald 3	14
10	10.08.2023	Groß Buchwald 3	3
11	11.08.2023	Groß Buchwald 3	3
12	14.08.2023	Groß Buchwald 3	1
13	14.08.2023	Groß Buchwald 2	5
14	16.08.2023	Groß Buchwald 3	3
15	17.08.2023	Groß Buchwald 3	1
16	18.08.2023	Groß Buchwald 3	4
17	21.08.2023	Groß Buchwald 2	2
18	21.08.2023	Groß Buchwald 1	6
19	22.08.2023	Groß Buchwald 3	12
20	23.08.2023	Groß Buchwald 3	3
21	25.08.2023	Groß Buchwald 3	1

22	29.08.2023	Trappenkamp	0
23	30.08.2023	Groß Buchwald 1	18
24	31.08.2023	Groß Buchwald 1	9
25	04.09.2023	WP Timmapse	0
26	05.09.2023	WP Timmapse	3
27	06.09.2023	WP Timmapse	21
28	07.09.2023	WP Timmapse	8
28	08.09.2023	WP Timmapse	2
30	11.09.2023	Groß Buchwald 1	2
31	13.09.2023	Groß Buchwald 2	9
32	14.09.2023	Groß Buchwald 2	32
Total			**237**

The Trappenkamp site is located in a gravel and sand extraction area east of Neumünster near the village of Tensfeld. The Groß Buchwald site is a field east of Bordesholm/Wattenbek near the Drögen Eider river where the mobile camera system was set up at three different locations only a few hundred metres apart.

By generating multiple data points of a flying bird (a maximum of approx. 12 per minute due to the system), a corresponding sequence of three-dimensional flight points/sequences is created. These time-stamped measurement points can then be used to reconstruct a flight path (track) with the corresponding positional accuracy.

A total of 12,024 red kite LRF points, divided into 237 flight sequences, were included in the analyses. In addition to the species of the bird surveyed, the location, the camera ID, the list of LRF points and other additional information such as date, number, flight behaviour and weather were also recorded.

5.2. AVES recordings

The two test wind turbines at the Gnutz-Timmaspe wind farm were equipped with two camera systems per turbine. The fields of vision of the cameras were orientated towards the east, as it was expected that red kites would primarily approach from this direction along the edge of the Iloo Forest (Figure 18).

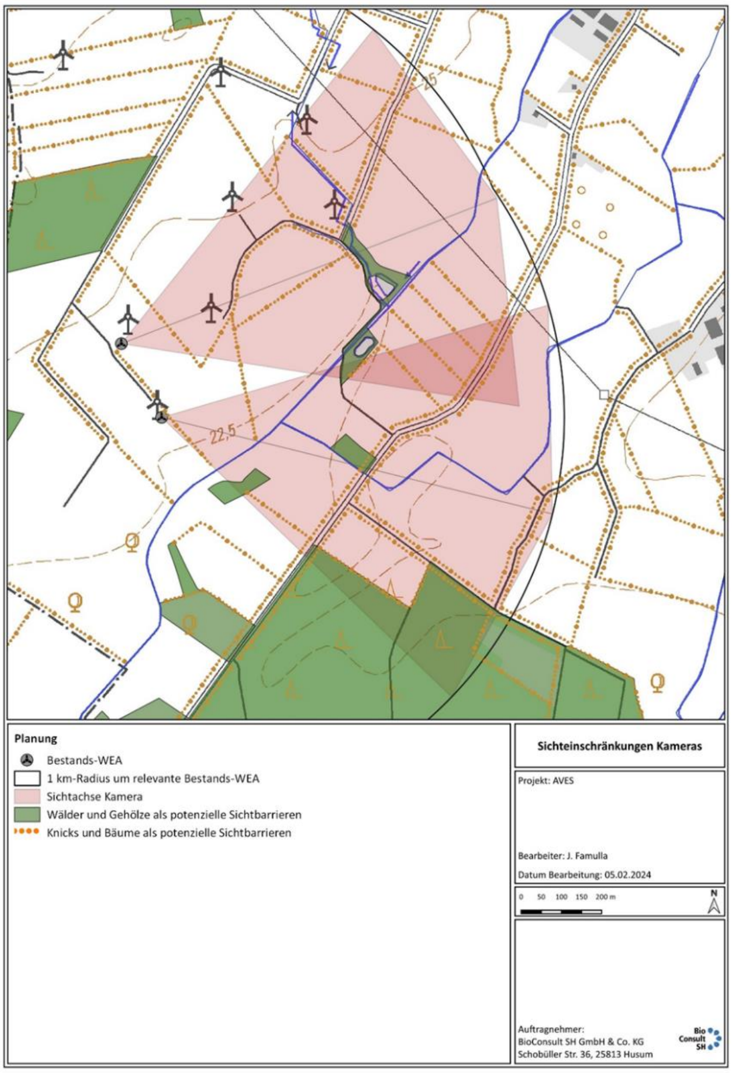

Figure 18: The orientation of the fields of vision of the cameras at the test wind turbines.

As described above in chapter 2.2, the cameras are so-called pan-tilt cameras. They are able to move both vertically and horizontally. This results in angles known as pan and tilt defining the area in which the cameras can operate. The necessary and possible pan angles of the cameras used on the wind turbines, i.e. the horizontal coverage area of each individual camera are shown in Figure 19.

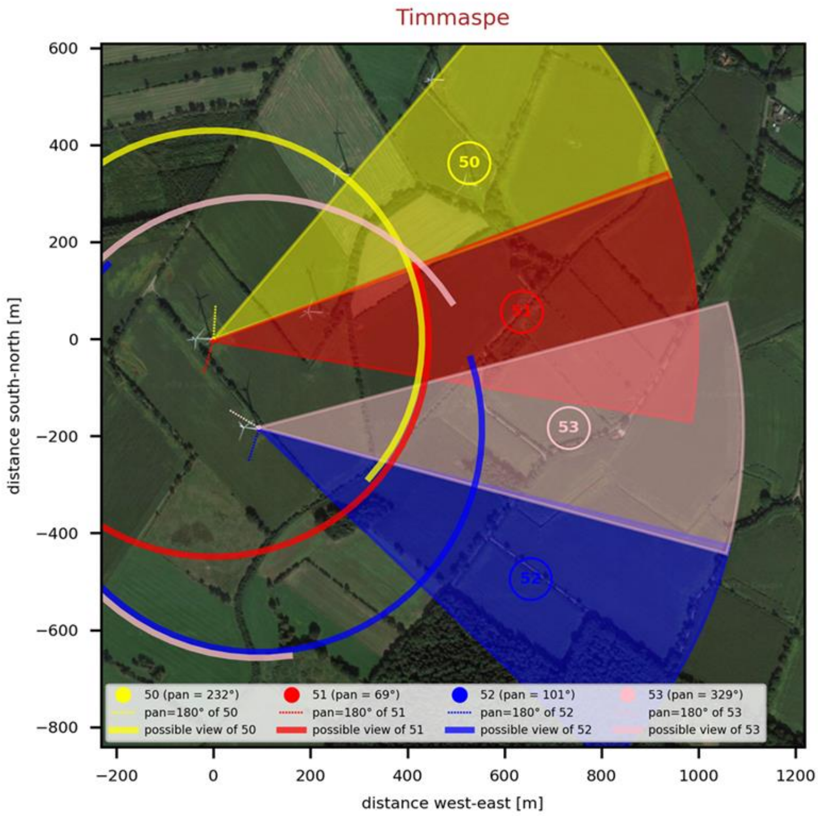

Figure 19: Pan angles of the installed cameras.

The vertical angles are called tilt. In this way, every point within a 1,000 m dome can be specified using a pan/tilt angle value (Figure 20).

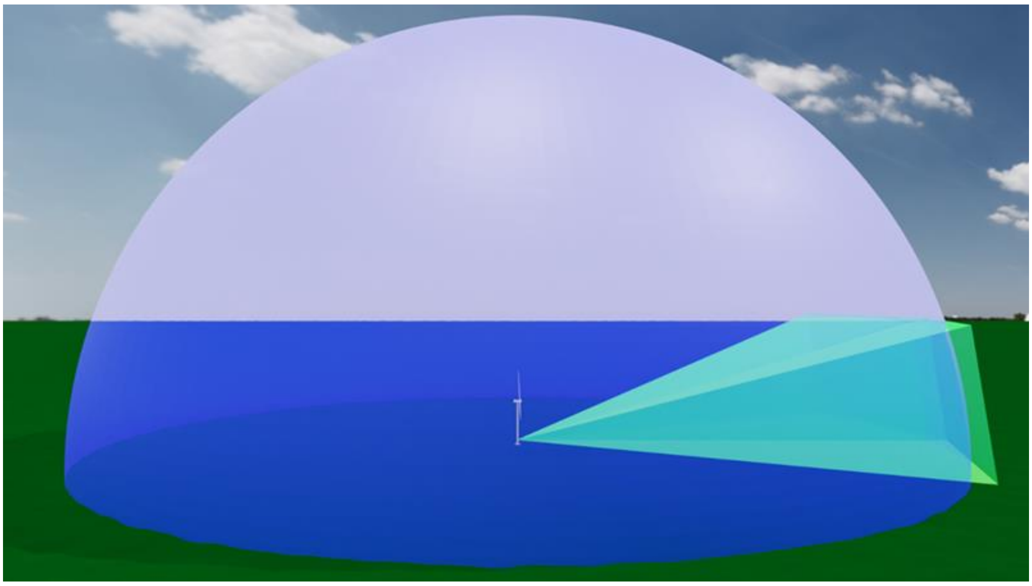

Figure 20: 1000 m dome covered by each of the cameras

Using a cross bearing of at least two cameras, every object within the range can be targeted and tracked. The corresponding pan/tilt values are saved as log files labelled with date and time.
The accuracy of the anti-collision system can be assessed by comparing the LRF points collected as reference data with the log files generated by the AVES cameras.

6. Statistical evaluation

The statistical analysis of the LRF points and the AVES log files was carried out by BIONUM GmbH – consulting in statistical ecology & biostatistics.

6.1. Method of the statistical evaluation

The data to be analysed are binary variables that are classified, for example, as “detected” or “not detected”. In the simplest case, it is possible to determine mean values of the corresponding rates. However, the variable is not normally distributed, so techniques that do not assume a normal distribution must be used to calculate the variance (e.g. to obtain confidence intervals).
In fact, the statistical situation is somewhat more complex, because time series are analysed and the LRF points are assigned to different individuals. This may lead to pseudo-replication (Stuart H., 1984) and thus result in underestimation of confidence intervals and biased calculated rates.
For this reason, an analysis strategy was used that adequately considers this data situation. The analysis was carried out using suitable regression methods, i.e. logistic regression methods, which belong to the generalised linear models (GLMs) (Benjamin M. et al., 2008; Field et al., 2012; A. Zuur et al., 2007). The allocation to different individuals was included by using the track ID as random intercept in the context of mixed modelling, which led to the class of generalised linear mixed models (GLMMs) (Benjamin M. et al., 2008; Pinheiro & Bates, 2000; A. F. Zuur et al., 2009). The temporal autocorrelation was analysed using pACF plots and integrated as a suitable autoregression structure (AR1) (Korner-Nievergelt et al., 2015; A. Zuur et al., 2007; A. F. Zuur et al., 2009). Please see the LfU testing framework for anti-collision systems (MEKUN 2024) for further details about method and background.
All statistical analyses were carried out using the open-source software R (R Core Team, 2023) and R package MASS (Modern Applied Statistics with S. Fourth Edition, 2002).
As the AVES Wind Onshore system is a multi-camera anti-collision system, the overall system was considered a single recording unit in the analysis of tracks or rates. Through exchange of data all cameras together trigger a distinct response of the overall system (i.e. a shutdown signal if necessary) but each camera is able to send a shutdown signal on its own without prioritising individual cameras.

7. Results

7.1. Requirements and effectiveness of bird detection

7.1.1. Total rate

The results for the total rate for the red kite are shown in Figure 21. Three slightly different ring-shaped detection areas with a torus of 200 m width were investigated. The average values are 85–87 % and the lower limits of the confidence intervals are 75–79 %, i.e. clearly above the 70 % required by the LfU testing framework for anti-collision systems.

It is required that the LRF-based observations are carried out at at least two different locations to be able to assess the robustness of the results and their transferability (MEKUN 2024). The AVES Wind Onshore system was tested and analysed at five different sites (see Chapter 5). If a significant difference ($p < 0.05$) in the total rates of both sampled sites is determined using suitable regression methods (see below), this difference has to be sufficiently checked for plausibility against the background of the different influencing factors of both sites and discussed in the context of transferability (MEKUN 2024). Data collected by the AVES Wind Onshore system were analysed using logistic GLMM regression methods to determine whether there are significant differences in the total rates between the different investigated areas.

This is not the case and all p-values are higher than or equal to 0.2 and therefore clearly not significant.

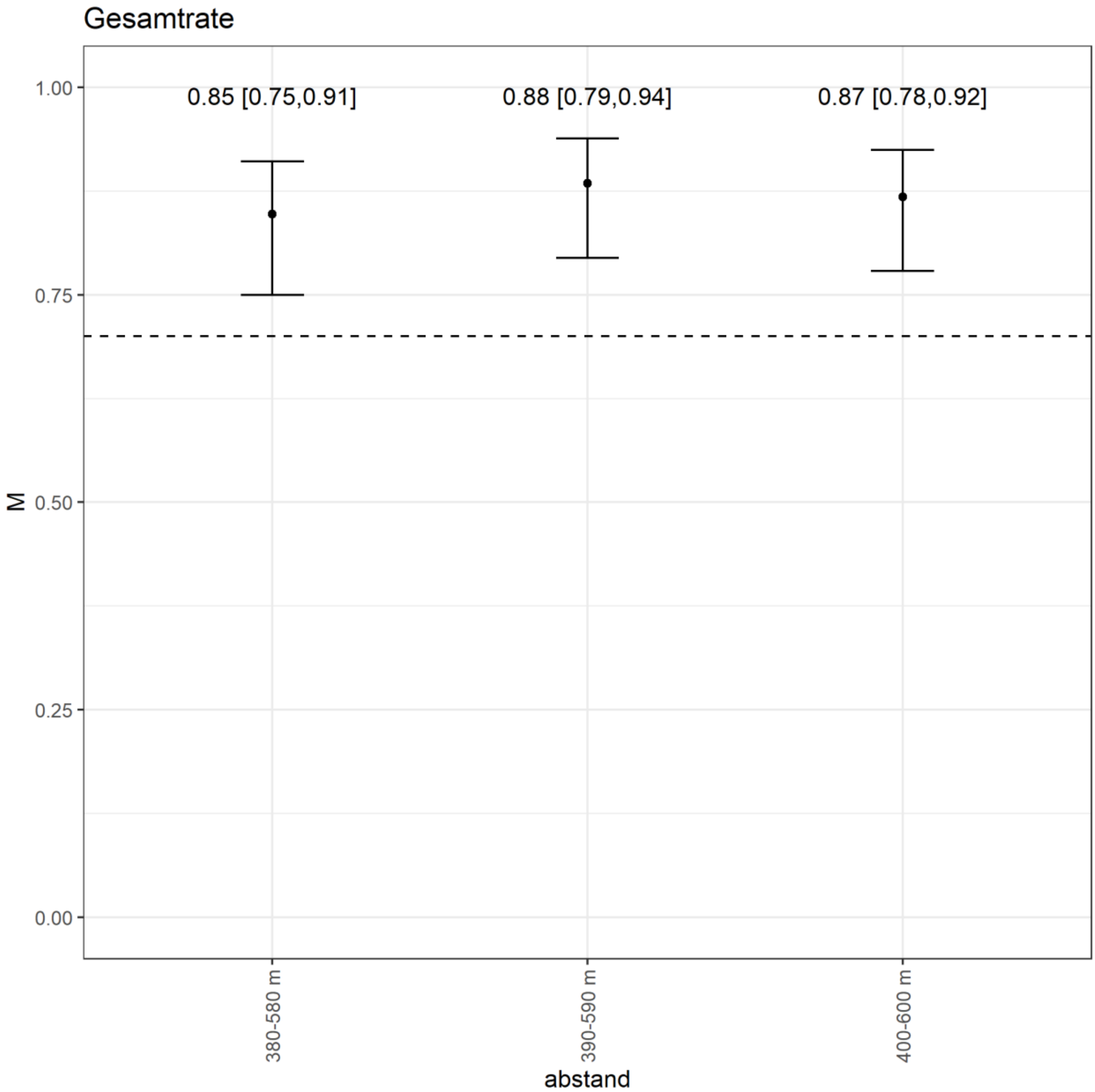

Figure 21: Statistical results for the total rate for red kite based on logistic GLMM analyses. Black dots indicate mean values, black bars 95 % confidence intervals.

7.1.2. Detection rate

The detection rate is not explicitly required according to the technical convention proposal "testing framework for anti-collision systems" (MEKUN 2024), but is rather implemented together with the identification rate (Chapter 2.) in the total rate. This rate is, however, useful for a better understanding. The results for the detection rate for the red kite are shown in Figure 22. Three slightly different ring-shaped detection areas with a torus of 200 m width were investigated. In all cases, the mean value is 95–97 % and thus well above the 75 % required in the KNE checklist (KNE 2021).

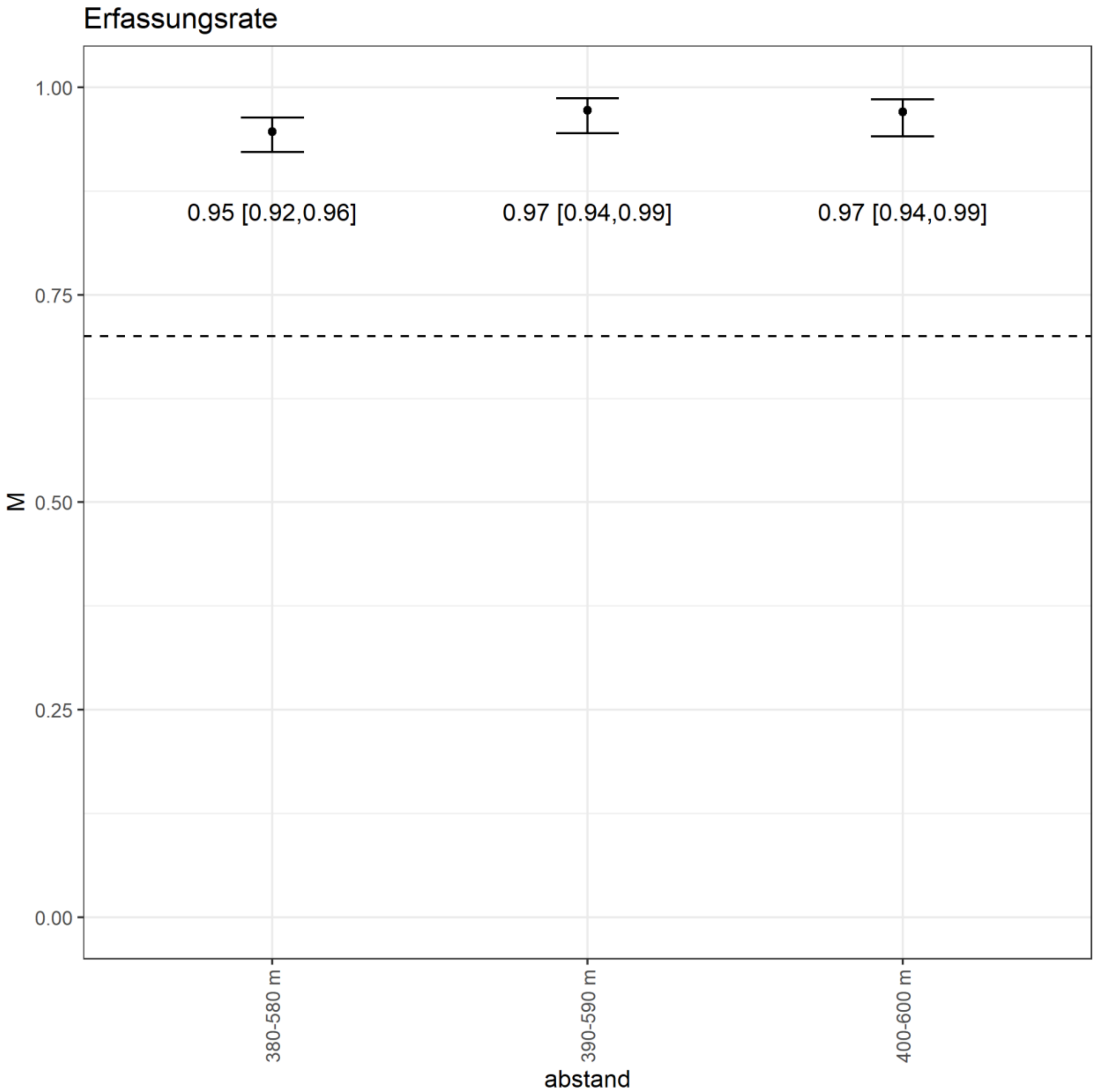

Figure 22: Statistical results for the detection rate for red kite based on logistic GLMM analyses. Black dots indicate mean values, black bars 95 % confidence intervals.

7.1.3. Identification rate

Just like the detection rate, the identification rate (see Chapter 2.) is not explicitly required according to the technical convention proposal "testing framework for anti-collision systems" (MEKUN 2024), but is included for better understanding (Figure 23). The presentation is based on the required values of the KNE checklist (KNE 2021). The results for the identification rate for red kite are shown in Figure 23. Three slightly different ring-shaped detection areas with a torus of 200 m width were investigated. The mean values are 87–98 % and thus well above the minimum value of 75 % required according to the KNE checklist and close to or above the desired value of (at least) 90 %. This data evaluation at different distances shows that the AVES Wind Onshore system specialises in longer distances. The system has a very high detection rate of 98 % up to a distance of 600 m.

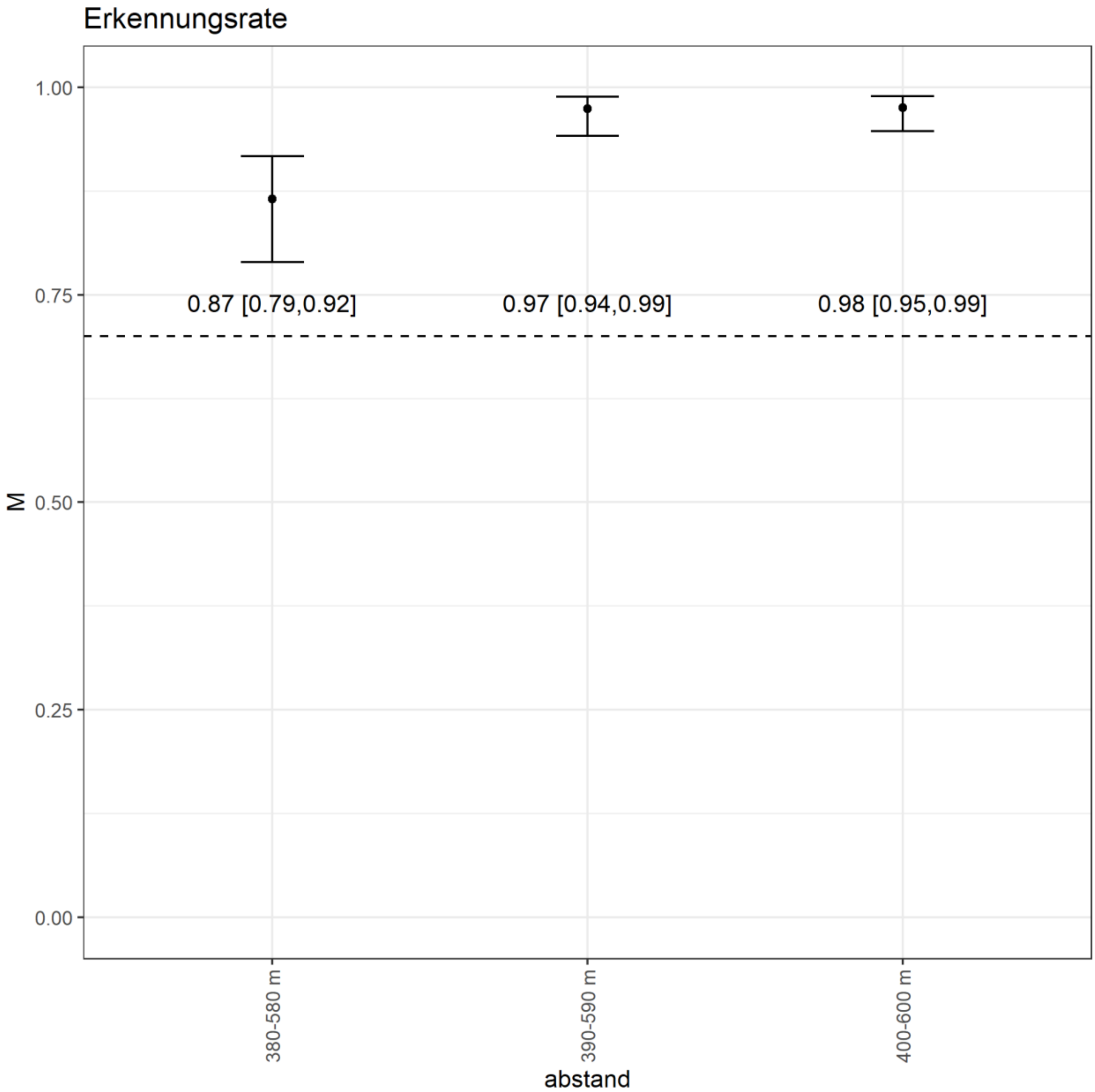

Figure 23: Statistical results for the identification rate for red kite based on logistic GLMM analyses. Black dots indicate mean values, black bars 95 % confidence intervals.

7.1.4. Coverage rate

For the validation test, four cameras were installed at two Nordex N149 wind turbines in a wind farm (see Chapter 5.2.). The field of view was selected to include increased red kite activity to be expected due to the high proportion of grassland.

A complete AVES Wind Onshore system would equip most of the outer wind turbines of a wind farm with cameras, resulting in a 360° surround view. Here only a part of the wind farm was equipped with cameras to simulate two wind turbines on the eastern edge of a larger wind farm.

Figures 18 and 19 in Chapter 5.2. illustrate that there are no significant visual barriers in the area of the field of view of the four installed AVES systems. The hedgerow structures are below the height of the installed cameras and the forests are at a sufficient distance for the cameras to look beyond these structures.

7.2. Temporal availability

To achieve a sufficiently high level of protection, a time availability of 95–98 % has to be ensured. This requirement was met during the validation of the AVES Wind Onshore system.

7.3. Influence and impact assessment

The influence and impact assessment serves to identify the effects and errors that could lead to an impairment of the proper functioning of the anti-collision system as a safety measure for bird protection (Table 2). The general product safety is not included; this is part of the CE declaration of conformity, which is a prerequisite for placing the product on the market (MEKUN 2024). In the present assessment of the AVES Wind Onshore system, all conceivable worst-case assumptions are included. There are two main categories: the risk analysis for the impact of weather conditions on the system and other ambient factors. The different weather conditions do not lead to insurmountable system failures of the AVES Wind Onshore system. An approach for to ensure proper functioning of the system is provided for each weather situation (Table 2). As all the camera systems used have the same hardware and software and communicate with each other, another or different system can always be accessed. The AVES Wind Onshore also offers different solutions for the second category, other ambient factors. The very flexible design of the system means that it is always possible to react project-specific by for example installing the cameras at different heights or in different quantities.

Table 2: Risk analysis for possible effects of ambient factors on the functionality of the AVES Wind Onshore camera system.

	Possible influence on the functionality of the camera system	**Worst case assumption**	**Result for detection (worst case)**	**Targeted test possible**	**Solution**
Weather conditions	General light intensity (brightness, twilight, darkness)	Low intensity leads to underexposure (no contrast) through long exposure time and possibly image noise.	False positives and false negatives	Twilight/darkness Simulation with drone	IR spotlight
		High intensity leads to overexposure (glare).	False negatives	Simulation with drone	Better adjustment of the automatic exposure
	Fog	Obstructed view	Detection difficulties	Testing in fog	Shutdown of the wind turbine if detection is not possible due to low visibility and the corresponding turbine cannot be switched to idle mode in time.
	Precipitation (rain, snow, hail, etc.)	Obstructed view	Detection difficulties	Testing during precipitation	Windscreen wipers
	Temperature	High temperatures – heat haze	Restricted detection	Testing when conditions occur	Automatic heating available, cooling system can be added if required, computers are equipped with fans. Additional sealing rings for the camera prevent the mechanism from freezing.
		High temperatures – system failure	No detection		
		Low temperatures – fogged lens	Restricted detection		
		Low temperatures lead to freezing of the moving components	Detection still possible but no pan/tilt		
	Reflexions	Ice, windows, water etc.	Restricted detection in the affected area, false negatives and false positives possible	Testing when conditions occur	Better adjustment of the automatic exposure

	Possible influence on the functionality of the camera system	Worst case assumption	Result for detection (worst case)	Targeted test possible	Solution
Further ambient factors	Heavy soiling of the lenses (dust, bird droppings, limescale stains, particles, etc.)	Soiling	Restricted detection by the affected camera	Not required	Camera cleaning system available
	Several moving objects at the same time	Overload of the system	Restricted detection	Testing when e.g. agricultural events attract many target species	Additional use of fixed cameras or further PTZ cameras, which still covers the field of vision of a cameras when it pans/tilts Each camera can detect up to 256 targets simultaneously. Zooming and panning/tilting leads to temporary loss of detections in the initial field of view.
	Landscape elements/changes in vegetation	Shading in the field of view	Restricted detection by the affected camera	Project-specific, not required	If possible, install of the camera elsewhere on the wind turbine, particularly higher up, but still below the rotor swept area.
	Heavy traffic, cultivation with heavy machinery, strong winds	Vibration, transmission of vibrations to the camera system	Restricted detection, blurred images	Testing during vibration events	AI also works with blurred images, switch to another camera, consider the location of the camera system.
	Proximity to transformer station, transformer, high-voltage	No negative effects are to be expected, as own fibre optic cables or the network of		Not required	Not required

	Possible influence on the functionality of the camera system	Worst case assumption	Result for detection (worst case)	Targeted test possible	Solution
	power line, radio relay line	the wind farm is used for communication. PC systems and cameras are protected against such influences in accordance with standards.			
	Power failure	System failure	System failure	Tested in Timmaspe wind farm	Battery

7.4. Development

7.4.1. Software development

Software development follows a predefined process. The individual steps of the process have been verified in suitable functionality tests to ensure that the software used fulfils its intended safety function (reduction of the collision risk of the target bird species) and that systematic errors are avoided.

A possible approach to the software development process is the V-model as for example described in DIN EN ISO 13849-1.

The AVES Wind Onshore system works with an understandable and comprehensible process but not every decision tree is directly comprehensible due to the use of an AI. As part of the software development, possible influences on the functionality of the AVES Wind Onshore system were tested and possible countermeasures developed.

Software specifications and the individual development steps, including the results of the tests to verify the respective development step, were documented internally. The documentation as well as document and quality management follow a standardised concept, which is based on the specifications of DIN EN 61508.

7.4.2. Hardware development

Like software development, hardware development follows a predefined process taking account of the entire life cycle of the safety function right from the development stage. The individual development steps have been verified in suitable functionality tests to ensure that the hardware used fulfils its intended safety function (reduction of the collision risk of the target bird species) and that systematic errors are avoided.

The hardware architecture was selected in such a way that the required reliability of the safety function is guaranteed.

The technical availability of the AVES Wind Onshore system is documented and comprehensible.

The interface between AVES Wind Onshore and the corresponding wind turbine is defined.

Integration into the wind turbine control system is evaluated for the respective type of wind turbine on a project-specific basis by an independent body to ensure that the signals of the AVES Wind Onshore system trigger the required response of the wind turbine.

As part of the hardware development, possible influences on the functionality of the AVES Wind Onshore system as a safety function were identified and possible countermeasures developed. Influences and measures were investigated within the framework of system validation. Systematic failures such as power failures or shutdown of individual wind turbines were taken into account in the validation.

Hardware specifications and the individual development steps, including the results of the tests to verify the respective development step, were documented internally. The documentation as well as document and quality management are based on the specifications in DIN EN 61508.

7.5. Operation phase

CE certification of the AVES Wind Onshore system guarantees safe commissioning and continuous operation in compliance with the requirements of the current Product Safety Act. These include the CE declaration of conformity and proof of ISO 9001 certification.

All further details on commissioning, continuous operation and servicing/maintenance are described in the accompanying standard operating instructions.

7.6. Data protection and data security

The provisions of the GDPR on the protection of personal data are complied with.

Access rights to the collected data are clearly specified and documented. Measures have been taken to prevent unauthorised access to the AVES Wind Onshore system and the collected data. Third-party access to the wind turbine control system via the interface between the wind turbine and the AVES Wind Onshore system can be excluded.

Further technical details on hardware, a description of the software, the operating instructions for the system and information on maintenance and servicing can be found in the Protecbird documentation supplied for AVES Wind Onshore.

8. Conclusion

8.1 Summary and comments

The AVES Wind Onshore System fulfils all of the requirements of the technical convention proposal "Testing framework for anti-collision systems" (MEKUN 2024) and achieves proof of effectiveness for the red kite.

The statistical analyses (BIONUM GmbH 2023) of the empirical data of the AVES Wind Onshore systems show that both the requirements of the LfU testing framework (MEKUN 2024) and the specifications of the KNE checklist (KNE 2021) are met for the red kite. From a species protection perspective, the AVES Wind Onshore system is a suitable protection measure for the red kite. It ensures that the species is detected from a sufficient distance and that idle mode is triggered on the affected wind turbine to minimise a significantly increased risk of killing the target species red kite. In accordance with Section 44 (5) No. 1 BNatSchG, it thus avoids the violation of the prohibition to kill under Section 44 (1) No. 1 BNatSchG and can therefore be used without restriction on wind turbines to accelerate the expansion of wind energy use in accordance with Section 6 of the WindBG.

The following project-specific response radius was calculated for the red kite:

Red kite: $r\_response$ = 385 m.

A detection area that forms a ring around the response area was chosen for the analyses (see MEKUN 2024). For better transferability to different possible situations in approval procedures, rings/tori of different sizes were analysed.

Detection, identification and total rates were specified in accordance with the technical convention proposal for anti-collision systems and analysed using suitable regression models. For all chosen response areas, these (or their confidence intervals) resulted for the above response area in values above the required minimum as defined in the testing framework for anti-collision systems and the KNE checklist. In addition, it was analysed whether the total rate differs significantly between the different detection areas. This is largely not the case (in all cases $p > 0.2$, i.e. not significant).

Data manipulation was ruled out by sending the Bioplan LRF data from Bioplan and the AVES system log files independently of each other to the statistical office BIONUM in Hamburg for analysis.

In summary, it can be concluded that the AVES Wind Onshore system adequately detects and identifies the red kite with regard to the requirements of the technical convention proposal (MEKUN 2024) and the KNE checklist and thus minimises the collision risk for this target species. The species protection requirements and the protective effect for the red kite are fully met by the AVES Wind Onshore system.

The AVES Wind Onshore System is recognised as a management system in accordance with the DIN EN ISO 9001:2015 standard.

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