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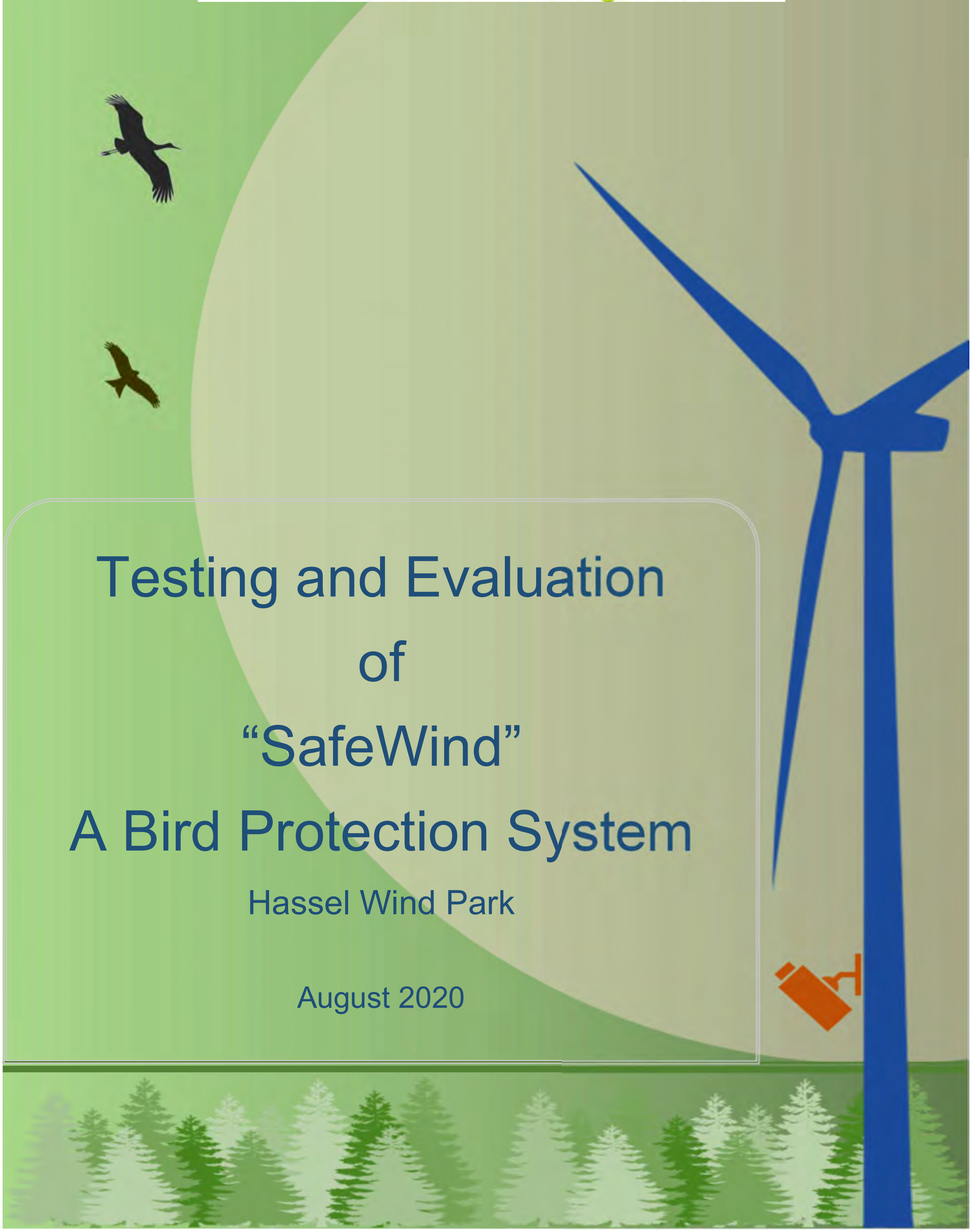

Testing and Evaluation of "SafeWind" A Bird Protection System

Hassel Wind Park

August 2020

TESTING AND EVALUATION

OF

“SAFEWIND”

A BIRD PROTECTION SYSTEM

HASSEL WIND PARK

AUGUST – 2020

Lackmann Phymetric

WestfalenWIND

SafeWind®

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Abstract

In Germany, the expansion of the wind energy in accordance with the species protection can only push the goals of German Energy Transition. In the present scenario, technical solutions (camera and radar) does not have sufficient scientific database on assessment of reduction of risk of collision of endangered species in German wind parks. Therefore, wind industry faces operational restrictions on existing wind turbines as well as reduced access to onshore wind potential area.

In beginning of 2018, WestfalenWind GmbH and Lackmann Phymetric GmbH took the initiative to test and evaluate SafeWind - a camera-based automated system by Biodiv-Wind SAS, France in their wind parks. At Lichtenau Hassel Wind Park, three SafeWind systems are installed at location (WEA 9, WEA 11 and WEA 13) and have been in operation since August 16, 2018. The SafeWind system works on principle of real time detection of flying object within intrusion area and triggering of regulation control of wind turbine, when the target is within the threshold limit. The aim of the test and evaluation of the SafeWind system was to create the decisive scientific database for its acceptance as an adequate mean to reduce the risk of collision of bird species like – red kite and black stork.

For uniformity in interpretation of the results, the evaluation protocol was adapted as per guideline published by KNE. In 2019, Dr. Karl Heinz Loske conducted the field study (between March and October) at Lichtenau Hassel Wind Park as an independent expert, Ph.D. Ecology, and submitted the report. The report from the expert is used as an input for the evaluation of the SafeWind system. Due to practical constraint on the field observation, only two wind turbines, WEA 11 and WEA 13 are considered for the study. The limiting parameters for the detection capacity (i.e. detection range) and regulation control (i.e. reaction range) were determined through the repeated Robird drone experiment. The dataset for the estimation of species-specific acquisition rate and collision risk probability were generated by applying the limiting parameters to the field observation data (LRF data) from Dr. Loske. In the dataset, it was assumed to consider the data between the installation height of camera and tip of the rotor blade (12 o'clock position) of respective wind turbines.

The detection range and the reaction range around the wind turbine were evaluated as 270 m and 172 m for red kite, and 337 m and 215 m for black stork from the Robird experiment. The acquisition rate is percentage of flying tracks detected by the SafeWind system out of all the flying tracks within detection range of respective species from the LRF data. At the rotor altitude of the wind turbine within the detection range, the acquisition rate for red kite is maximum, 84% at WEA 11 and 93% at WEA 13. In case of black stork, it is 100% only with one wind turbine (WEA 11) but may not be meaningful due to less number of the observation points. Below the

rotor altitude of the wind turbine and within the detection range, the acquisition rate for red kite is comparatively lower, 83% at WEA 11 and 76% at WEA 13. In general, the acquisition rates were expected to reduce gradually outside the detection range. However, this reduction is neither systematic nor homogeneous and linear. For example, the acquisition rate for red kite is surprisingly increasing with the distance in case of WEA 11 and reach up to 88% in the zone 2 (270 m – 300 m). The hypothesis is that the other factors than distance, altitude and position of bird may influence the acquisition rate. While investigating the non-acquisitions, it was observed that the topography and kind of background (vegetation, other wind turbines, deep dark sky) around the wind turbine may influence the acquisition rate. The topography and the background have a relation with the installation height of camera (In our case, the installation height was selected due to the turbine-specific constraint). The site-specific adjustment on the installation height of camera thus can improve the acquisition rate of the system.

The collision risk probability is the measure of effectiveness of reaction of the SafeWind system from the reaction range. A worst-case scenario, direct flights of each track of red kite at their average speed from the reaction range distance towards the wind turbine rotor and their inability to anticipate the moving object, were assumed for the calculation of the collision risk probability. When the time taken to reach to the rotor is less than the time needed to bring the rotor to the safe rotational speed (idle speed = 50 kmph of blade tip speed), respective tracks are declared, hypothetically, as a collision with the rotor. Considering the reaction range adopted for this experiment, the collision risk probability for red kite is determined as 9% at WEA 11 and 12% at WEA 13. These probabilities of risk of collisions appear highly overestimated. When the reduction factors like varying operational speeds of the wind turbine, biological avoidance behaviour of red kite can eliminate the overestimated risk of collision. Based on learning from the SafeWind recorded videos, the red kite has obvious anticipation behaviour while passing through the rotor. For quantifying the anticipation behaviour, bird-vehicle collision studies for turkey vultures (DeVault, 2014) are referred which resulted in reduction of probabilities to 3% at WEA 11 and 8% at WEA 13 due to anticipation behaviour of birds of prey below 90 kmph speed of the moving object. Moreover, empirical data of Bird Sentinel from Biodiv-Wind shows that collision events of red kite in France (n=7) and in Germany (n=1) detected by the SafeWind up to now were only recorded when blade tip speed was above 130 kmph. Considering this, the collision risk probability in our case is 0%. Indeed, the collision of any bird species is reported neither during the study period nor from the day the SafeWind system is in operation.

To sum-up, the use of the SafeWind system at wind turbines, which has the maximum acquisition rates (84% at WEA 11 and 93% at WEA 13 in the critical risk of collision zone) within the detection range and the low theoretical collision risk probability (9% at WEA 11 and

12% at WEA 13) within the reaction range for red kite, shows the significant reduction in the risk of the collision. Despite the limited numbers of observations for black stork, the reduction in the risk of collision is also applicable. Such system can also reduce the risk of collision for other species like common buzzard, black kite and kestrel found around the study area. At last, the outcome of the evaluation will enable the authorities to decide on accepting the SafeWind system as an adequate mean to reduce the risk of collision of the impact sensitive bird species from the wind turbine.

M.Sc. Bhavin Soni   Dipl.-Ing. Johannes Lackmann   Dr. Jan Lackmann

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1. Introduction

The expansion of wind energy is vital to meet the goal of German Energy Transition. The expansion has to proceed in accordance with protection of bird species of respective region. Out of many bird species, red kites and black storks found to have a risk of collision with wind turbine (WEA). Due to lack of actual assessment on risk of collision, the legal provisions are imposed on operation and new planning of the wind turbines. The spectrum of restriction ranges from need-based shutdown during the agricultural activities around the wind turbines to the daytime shutdown during entire breeding period (beginning of March until end of October) for the protection of impact sensitive large and raptor species.

The system solutions, like radar and camera, exist which recognize the birds within the vicinity of the range, record their movement and regulate the wind turbine when birds are entering in the pre-defined threshold limit around the wind turbine. These automated systems bring the rotor to the idle operational state such that the risk of collision either is reduced to the minimum or is eliminated. The system automatically restarts the wind turbine, when the birds are out of threshold limit.

These systems have been accepted in country like France as a possible solution for reducing risk of collision of impact sensitive bird species with wind turbines. In case of Germany, there is a lack of scientific database on performance of these systems on German wind parks for decision-making on acceptance by authorities at regional as well as country level.

In beginning of 2018, WestfalenWind GmbH and Lackmann Phymetric GmbH started a project to address the problem of collision with wind turbines for impact sensitive large and raptor species – red kite and black stork at Lichtenau-Hassel wind park. Three camera based video surveillance system - SafeWind® (SafeWind), were installed on three different wind turbines at this wind park and are in operation since August 16, 2018.[1] Lackmann Phymetric GmbH developed a protocol for evaluation of SafeWind system and later adjusted to the criteria defined in KNE guideline (KNE, 2019) for uniformity in interpreting the results.

Quantification of performance parameters of the system makes decision-making process easy. As SafeWind system works on detection and need-based regulation of wind turbine, it is important to know – capacity of detection as detection range around the wind turbine; effectiveness of detection as acquisition rate of the system within the detection range;

[1] Only two wind turbines are part of this study due to practical constraint from field expert

regulation control as reaction range of system around the wind turbine; and effectiveness of regulation control as collision risk probability.

Keeping focus on these parameters, following four objectives were assigned to the evaluation:

- Evaluate the species-specific detection range of the SafeWind system
- Evaluate the species-specific reaction range of the SafeWind system
- Evaluate the acquisition rate of the targeted species by the SafeWind system
- Evaluate the collision risk probability of the SafeWind system

For evaluation of the SafeWind system, there has to be a comparable database, which can be collected by using secondary technical systems and field survey of targeted bird species by the expert ornithologist. Dr. Karl Heinz Loske and M.Sc. Carl Henning Loske (expert) conducted the field observation study of targeted bird species by using secondary technical system as Laser Range Finder (LRF) at Lichtenau Hassel Wind Park, submitted the report and the LRF data (Loske, 2020). The outcome of the field study and the LRF data are used as an input while evaluating the SafeWind system.

Another secondary technical system as Robird drone was used in the study to generate the comparable database for evaluation. The specification of Robird drone are as per Annexure - I.

2. Main characteristics

Characteristics of wind turbines and SafeWind system, used in this study, are elaborated in this chapter.

2.1. Wind turbines

Two wind turbines, WEA 11 and WEA 13, are equipped with SafeWind systems at Lichtenau-Hassel Wind Park and have characteristics as per Table 1. Figure 1 represent the location of both wind turbines at Lichtenau Hassel Wind Park.

Table 1 Characteristics of wind turbines

Characteristics	WEA 11	WEA 13
UTM co-ordinates (UTM 32)	E 32491260	E 32491998
	N 5725072	N 5724864
Model	E-92	E-115
Nominal power (kW)	2350	3000
Manufacturer	Enercon	Enercon
Hub height (m)	138.0	149.5
Rotor diameter (m)	92	115.8
Total height (m)	185	207
Rotational speed at full operation (RPM)	16	12.8

Figure 1 Location of WEA 11 and WEA 13 at Lichtenau Hassel wind park (highlighted with red circle)

2.2. SafeWind

The SafeWind, a camera based video surveillance system, from Biodiv-Wind SAS, France was installed on WEA 11 and WEA 13 and in operation since August 16, 2018. The characteristics of both installed SafeWind systems are identical and represented in Table 2. Figure 2 shows the photos of installation of the SafeWind system at WEA 11.

Table 2 Characteristics of SafeWind system

Characteristics	SafeWind	
Manufacturer	Biodiv-Wind SAS	
Number of cameras	8 HD IP 66	
Position of cameras on tower	2 x 90°	
Focal length (mm)	2.8	
Field of view of camera	103° x 60°	
Resolution of cameras	12 fps (video) with 1920 x 1080 pixels	
Installation height (m)	46 (WEA 11) and 52 (WEA 13)	
Coverage area around wind turbine	At camera height	360° (horizontal), 240° (vertical)
	At rotor height	360° (horizontal), 360° (vertical)

Figure 2 Installation photos of SafeWind system at WEA 11

Functional principle is based on detection, deterrence and regulation. Due to prior agreement with local authorities, deterrence through speakers are deactivated and not part of evaluation too.

The un-used through holes for red aviation lights on wind turbine concrete tower were chosen for mounting of the camera at the respective wind turbines, 46 m on WEA 11 and 52 m on WEA 13.

The detection and the regulation control depends on pixel size of the flying object and duration of stay within the intrusion area. Moreover, these parameters (size and time) for detection and regulation can be set differently. At Hassel Wind Park, these parameters were selected optimistically, means higher detection range than reaction range. Figure 3 shows graphical representation of the system functionality. Here, it is important to note that the sensitivity set is not the maximum sensitivity the SafeWind could reach.

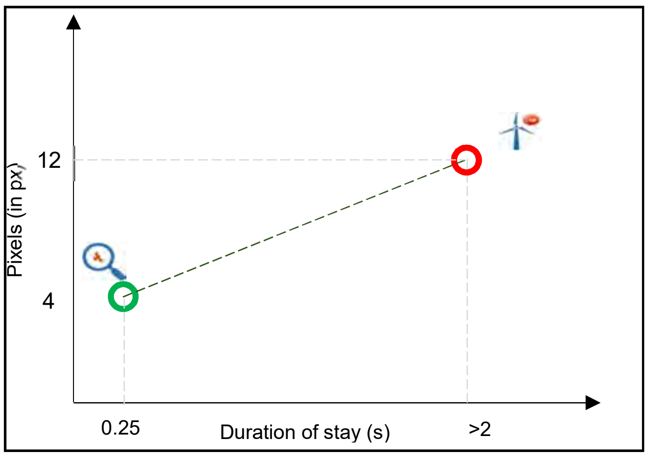


Figure 3 Graphical representation of detection (green circle) and regulation (red circle) functions of SafeWind system

The SafeWind system records events as a video of intrusions and written in a specified nomenclature, which later analysed by ornithologists at Biodiv-Wind and uploaded on the server for access to customer. An example of the nomenclature of recorded file is as follows:

A			B			C	D	E
2019	06	09	10	12	38	CAM 4	200kmph	ON

A: Date of intrusion recording

B: Timestamp (hh:mm:ss) of either detection or regulation

C: Camera position from which intrusion recorded

D: Tip speed of rotor blade at the time of detection or regulation

E: Status on execution of signal for detection or regulation

3. Methods

Evaluation of the SafeWind system requires quantification of ability of reduction in risk of collision of protected bird species at wind turbine.

The quantification estimated as –

1) Acquisition rate within collision risk zone (CRZ); and

2) Effectiveness of system reaction through collision risk probability (CRP).

An experimental approach is used for estimating the parameters for acquisition rate and collision risk probability of the SafeWind system. These parameters are – 1) Detection range (D_R), and 2) Reaction range (R_R).

Detection range is the horizontal ground distance around and from the centre of the wind turbine base within which the SafeWind system must be capable of detecting the flying bird species considering the field of view of camera.

Reaction range is the horizontal ground distance of flying bird around and from the centre of the wind turbine base from which the SafeWind system should be capable to trigger the shutdown control of wind turbine.

Reaction range is included within the Detection range.

3.1. Estimation of detection range and reaction range

In the experiment, flights of Robird drone, a remotely piloted robotic Peregrine Falcon, were conducted towards and around the wind turbine (WEA 13). Figure 4 shows the area within which all flights of the drone were steered. Before starting the flight of drone, time stamps of the Robird and the SafeWind system were matched and recorded. The difference was adjusted while comparing of drone flight data with the recorded videos of detection and regulation by SafeWind system. The output of the Robird flights was in CSV and KMZ format that gave information about GPS co-ordinates and altitude of Robird for each time stamp. Time interval between each data point was 20 ms (millisecond).

For each flights of the Robird, SafeWind system can record more numbers of videos due to approach angle, direction and altitude of the flight. As explained in chapter 2.2, timestamp of each video filename is the instance of either detection or regulation. These instances were compared with the flight data of the Robird drone to find GPS location of the Robird. The GPS co-ordinates of matched instances were plotted on the Google Earth file and horizontal ground distance from the co-ordinates of the wind turbine were measured. Detection distance as horizontal distance at the start of detection and reaction distance as maximum horizontal distance of regulation initiation were determined for each flights of the Robird drone.

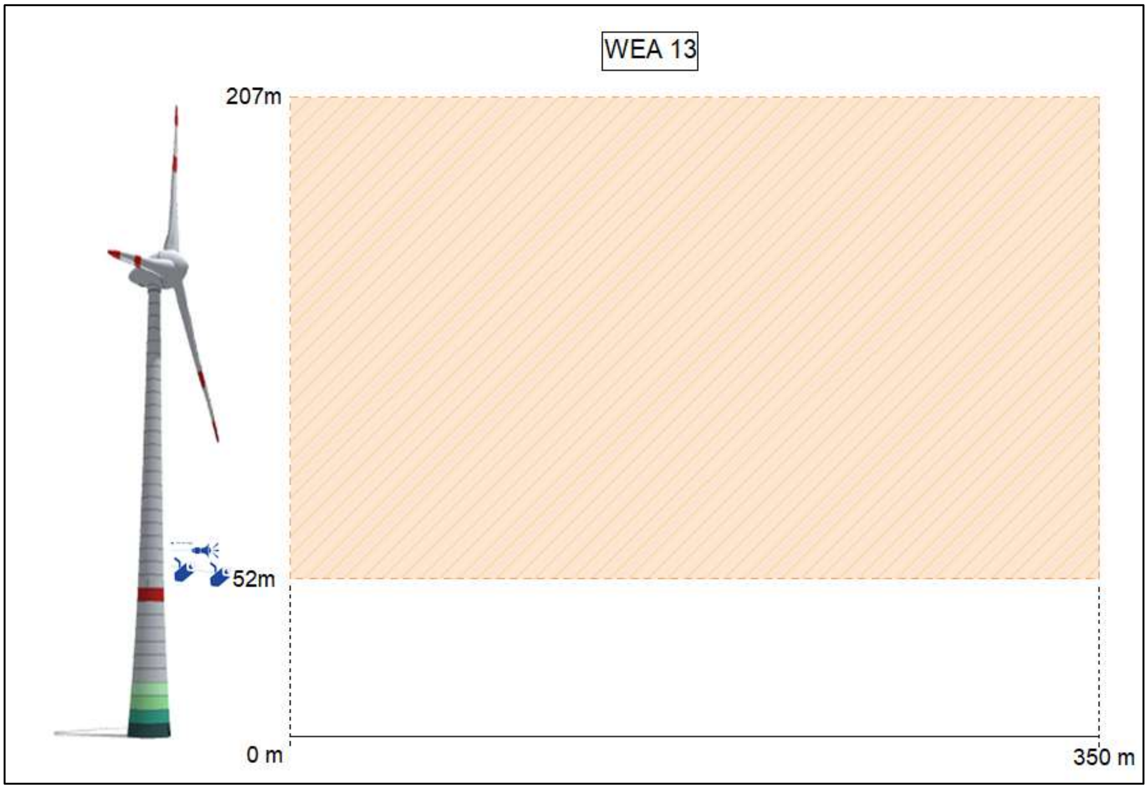


Figure 4 Robird drone flight plan (Orange rectangle with hatches - Horizontal distance: 0m - 350m; Altitude: 52m – 207m)

Detection range and reaction range were derived by averaging the outcomes of each Robird drone flights.

As per expert ornithologists at Biodiv-Wind, the actual size and surface area of red kite and black stork are bigger than Robird drone and therefore, it is necessary to apply size factor to the results of Robird drone to get the species-specific detection range and reaction range. The detection range and reaction range for red kite and black stork was estimated by applying size factor 2 and 2.5 respectively, to the results of Robird drone. The detection range and the reaction range are the controlling parameters to estimate the acquisition rate and collision risk probability respectively.

3.2. Estimation of Acquisition Rate

An acquisition rate is the percentage of tracks of flying object detected by the SafeWind system from all the tracks of flying object within the detection range. The LRF data from expert contains observation points of different species of birds other than targeted species – red kite and black stork. Figure 5 shows the graphical representation of the LRF data. For this report, observation points and their respective tracks pertaining to red kite and black stork are evaluated from LRF data for deriving acquisition rate. As the SafeWind systems at both the wind turbines (WEA 11 and WEA 13) are part of evaluation, horizontal ground distance of each flight observation points from respective wind turbines were calculated by using "Haversine formula" (Wikipedia, 2020).

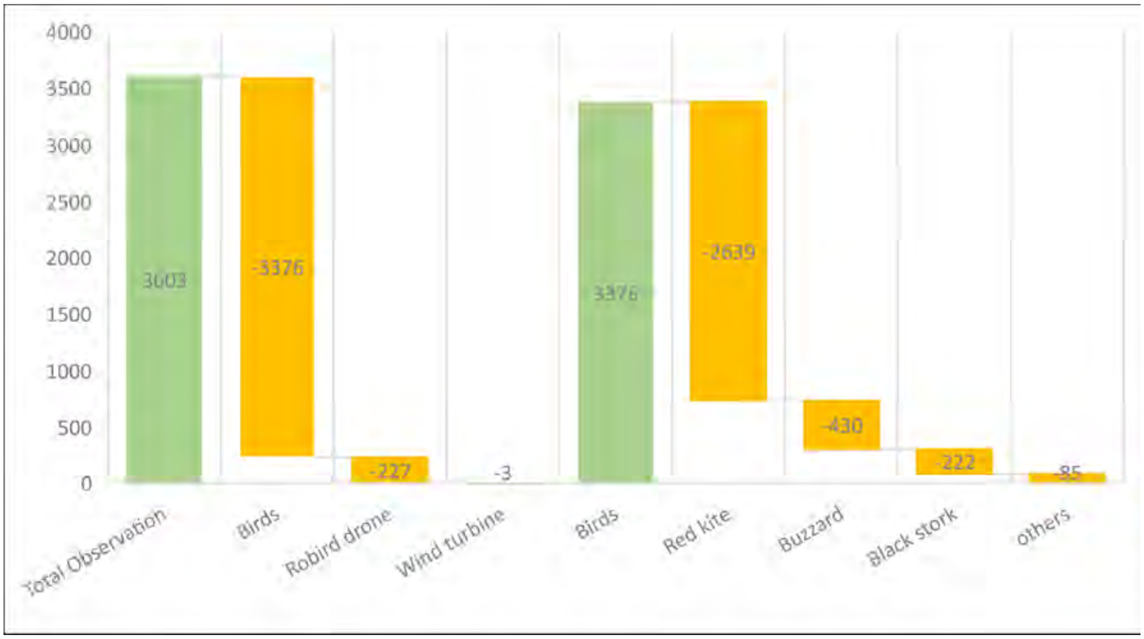


Figure 5 Analysis of LRF data from the expert

It is expected from the SafeWind system that the acquisition rate in the risk of collision area should be as highest as possible. The tracks of bird species are at highest risk of collision, when they are flying towards and/or within the rotor altitude. When these bird species are flying around and/or outside the rotor altitude, the risk of collision is less compared to the previous case. Therefore, it is necessary to estimate and distinguish the acquisition rate for both risk areas within detection range of respective species. To understand the detection capacity of the SafeWind system beyond the derived detection range, it is assumed to determine the acquisition rate for additional 30m and 60 m from the derived detection range. To limit the risk zones other than at rotor altitude, it is assumed to consider the observation points of tracks between the installation height of camera and tip of the rotor blade, when the rotor blade is at 6 o'clock position, on the respective wind turbines. This has resulted in classification of collision risk zones (CRZ) for which the acquisition rate in each zones is to be determined. The classification of collision risk zones are shown in Figure 6. The ranking of zones represent the level of criticality for risk of collision of targeted bird species. It means – zone 1 is most and zone 3 is least critical in rotor altitude, whereas, zone 1a is most and zone 3a is least critical outside rotor altitude.

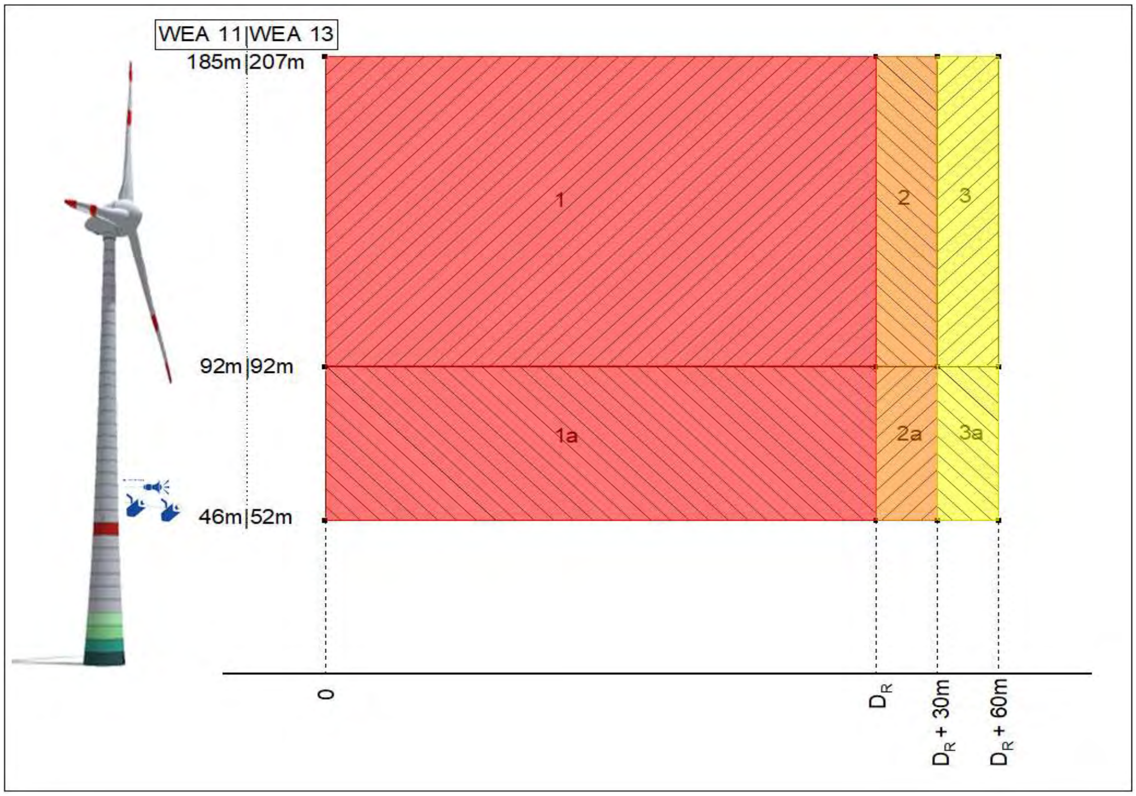


Figure 6 Classification of Collision Risk Zones (CRZ) (D_R – Detection range in m; 1, 2 and 3 – within rotor area; 1a, 2a and 3a – between camera position and blade tip at 6 o'clock)

To confirm the acquisition, timestamps of recorded videos of the SafeWind system for respective wind turbines were compared with the timestamps of each flight tracks from LRF data (Loske, 2020) within the collision risk zones. Matched videos of detection and/or regulation were further compared with the co-ordinates of bird species, field of view of camera from which instance is recorded and landscape around the flight of bird species. To declare the confirmed acquisition of the track, it was assumed there should be minimum one matching video of detection or regulation for the entire track.

For each collision risk zones, percentage of confirmed acquisition from total flight tracks were calculated to get the zone specific acquisition rate for red kite and black stork.

3.3. Estimation of Collision Risk Probability

A Collision Risk Probability (CRP) is the theoretical calculation of the percentage of possible risk of collision of tracks out of all the tracks of targeted species within the reaction range. The possible risk of collision is estimated, when time required to reach to the rotor area by the targeted species is less than the time required to bring the rotor to the safe rotational speed upon activation of shutdown control by the SafeWind system. Here, it is assumed that the flight of each tracks are directly towards the rotor area and starting from the reaction distance, though it is not true in reality. Flight speed of each tracks of targeted species are referenced from the LRF data (Loske, 2020). The time required to reach to the rotor area for each tracks are derived from the mathematical relation between distance of species-specific reaction range and average speed of the respective tracks.

When the targeted species are flying within the derived reaction range, the SafeWind system triggers the shutdown control of wind turbine. Duration for complete stop of the rotor rotation depends on control parameters defined by the wind turbine manufacturer. As per Enercon, it takes 35 s for complete stop of the rotor from the full operation for both wind turbines. However, it is only necessary to bring the rotor to the safe rotational speed from the respective operational speed of rotation for eliminating the risk of collision (KNE, 2019). The SafeWind system monitors the rotational speed of rotor through the blade tip speed, measured in kmph. When the tip speed of the rotor blade reaches to 50 kmph (idle speed), the rotor speed is defined as safe rotational speed and SafeWind system logs the time taken to reach to 50 kmph of the blade tip speed. The duration varies due to different operational speeds of rotor at the time of shutdown control from the SafeWind system. For this report, maximum duration, as a worst-case scenario, is considered for each wind turbine type in calculation of the collision risk probability.

The SafeWind system triggers the shutdown control, when the size of the flying object reaches a parameterized threshold and considering the duration of stay in the intrusion area of camera. Numerically, for installed SafeWind systems, the duration of stay of flying object in the intrusion area of camera is set as minimum of 2 s of continuous detection within the reaction range for triggering the shutdown control. However, the flight characteristics of targeted species in different scenarios (like gender, age, hunt for food, , migration and so on) and practical constraints to note the approach angle of each observation points by the expert in the field from perspective of the camera are not part of this report. Therefore, the tracks of targeted species may not have explanation on no regulation event, when flying within the reaction range around the wind turbine. This is the reason for the assumption of the direct flight towards the wind turbine, starting from the reaction distance.

4. Results

4.1. Evaluation of detection range and reaction range

On 9th October 2019, 8 flights of the Robird drone experiment were conducted between 11:00 a.m. and 2:00 p.m. in presence of the expert. Comparison of one Robird flight in Google Earth is shown in Figure 7 as an example. Compiled outcome of all Robird drone flights as detection distance and reaction range with respective altitude are illustrated in Table 3.

Figure 7 Robird drone and SafeWind comparison (green – flight track of Robird drone; yellow pin – matching SafeWind videos; red pin – shutdown initiation; red circle – wind turbine rotor area; light blue circle – position of WEA 13)

The detection distance is the instance, when the SafeWind system started the detection of the Robird drone and the reaction range is the instance, when the SafeWind system initiated the shutdown control of wind turbine. Out of all eight flights, the shutdown control did not triggered in one flight at 12:13 pm though the Robird drone was detected. Figure 8 and Figure 9 show graphical representation of detection distance and reaction range respectively.

Table 3 Compiled results of Robird drone flights and SafeWind videos

Robird Flight	Starting Time [hh:mm:ss]	Detection		Reaction	
		Distance [m]	Altitude [m]	Distance [m]	Altitude [m]
1	11:20:17	145	82	71	99
2	11:43:00	146	103	74	101
3	12:01:15	167	129	49	122
4	12:13:06	151	155	No	No
5	12:39:33	160	153	45	155
6	12:49:52	73	161	145	143
7	13:31:33	135	141	124	218
8	13:42:19	100	53	95	53

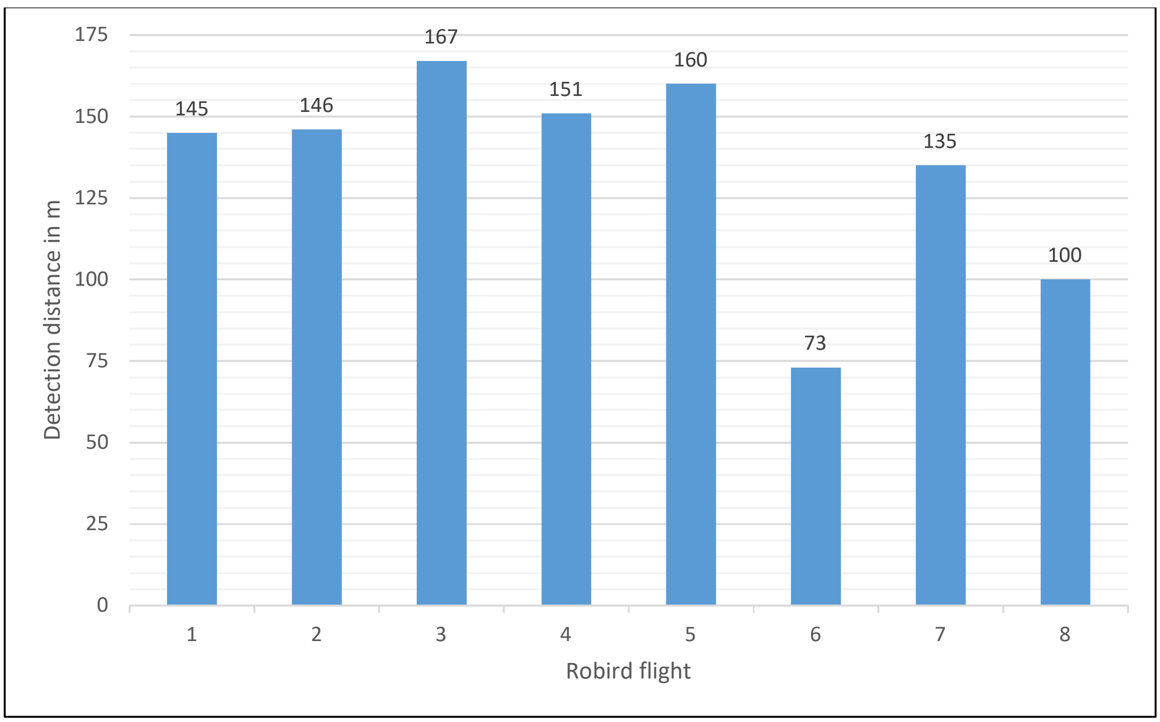


Figure 8 Detection distance of Robird drone flight by the SafeWind system (n = 8)

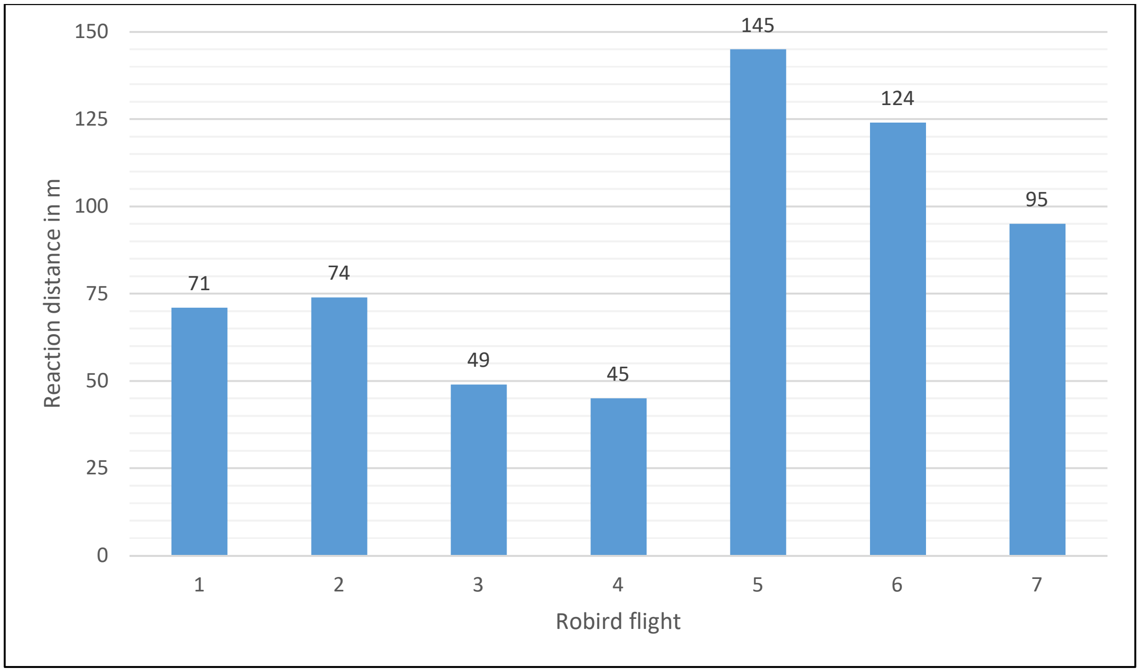


Figure 9 Reaction distance of Robird drone flight by the SafeWind system (n = 7)

The averaged detection distance of Robird drone flights as 135 m resulted in the species-specific detection range as 270 m for red kite and as 337 m for black stork upon application of size factor 2 and 2.5 respectively. It is represented graphically in Figure 10.

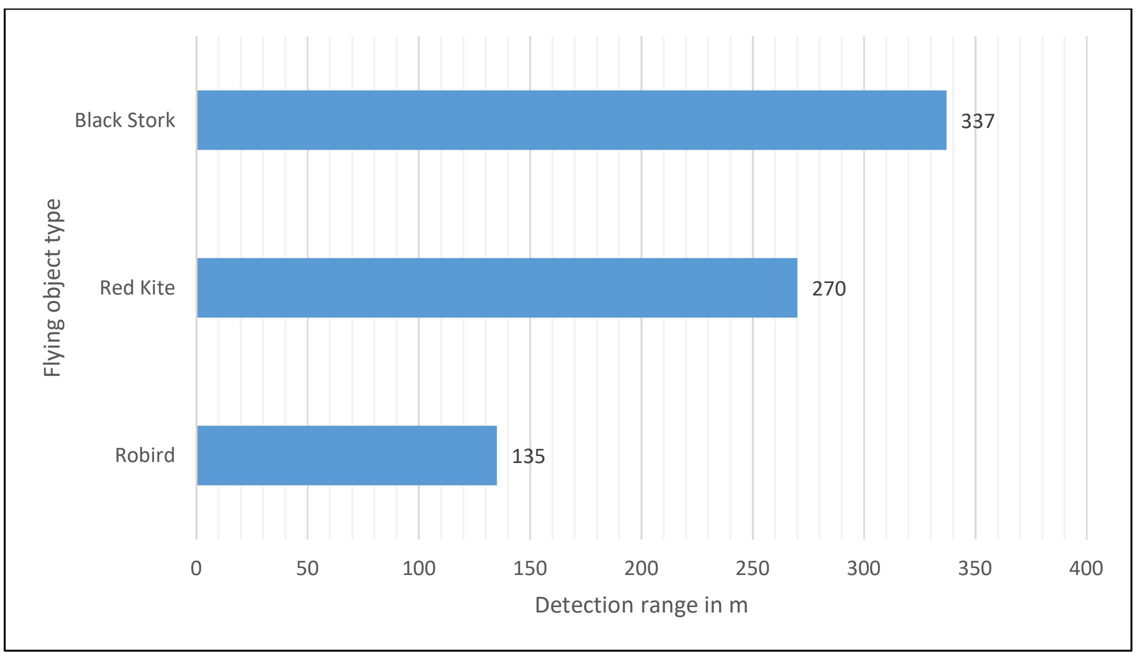


Figure 10 Species-specific detection range for SafeWind system

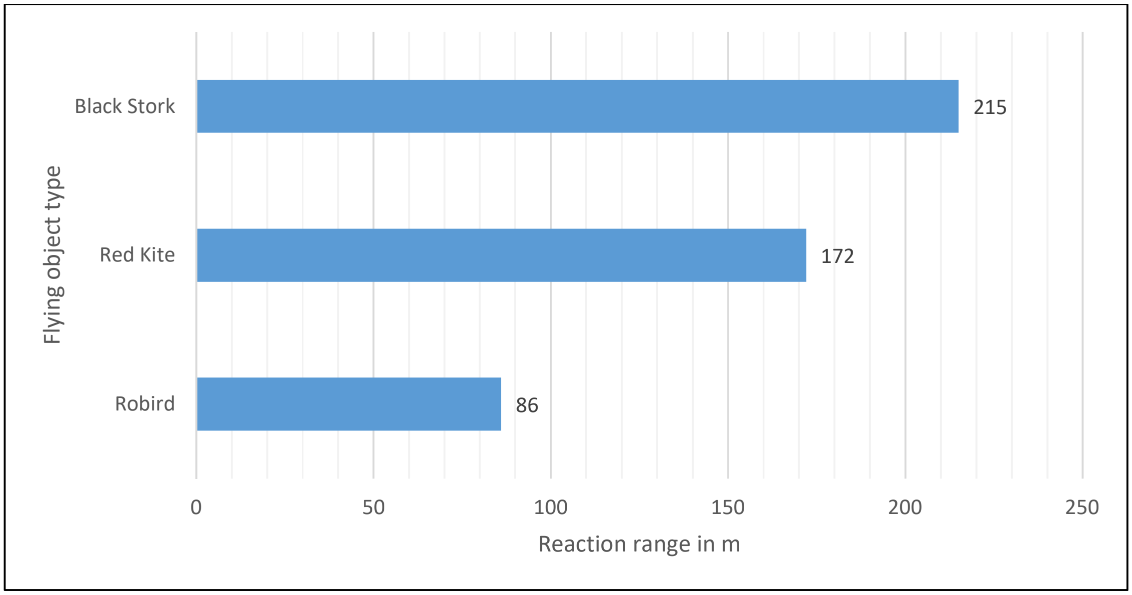


Figure 11 Species-specific reaction range for SafeWind system

The averaged reaction distance of the Robird drone flights as 86 m resulted in the species-specific reaction range as 172 m for red kite and 215 m for black stork upon application of size factor 2 and 2.5 respectively. It is represented graphically in Figure 11.

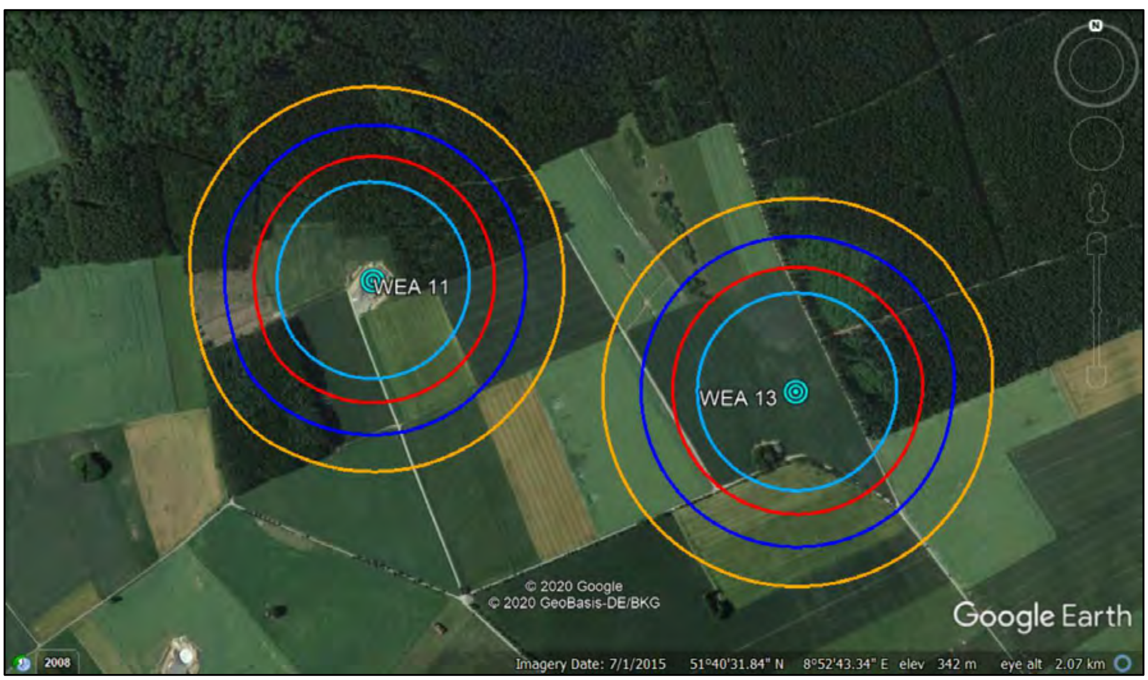


Figure 12 Pictorial representation of species-specific detection range (red circle – red kite; orange circle – black stork) and reaction range (sky blue circle – red kite; dark blue circle – black stork) around WEA11 and WEA 13

Pictorial representation of the evaluated species-specific detection range and reaction range at both the wind turbines on Google Earth are shown in Figure 12.

4.2. Evaluation of acquisition rate

4.2.1. Input data

The outcome of the species-specific detection range from Robird experiment and the limits of collision risks as explained in chapter 3.2 were applied to the LRF data to evaluate acquisition rate for both the wind turbines. Number of observation points under study are illustrated in Figure 13. From LRF data, 31% observation points of red kites and 50% observation points of black storks are part of the evaluation. For estimating the acquisition rate at each wind turbines, observation points, 61% for red kite and 94% for black stork at WEA 11, whereas, 39% for red kite and 6% for black stork at WEA 13, are considered. Position of each observation points within detection ranges around the wind turbines are plotted in Google Earth and shown in Figure 14 for red kite and Figure 15 for black stork.

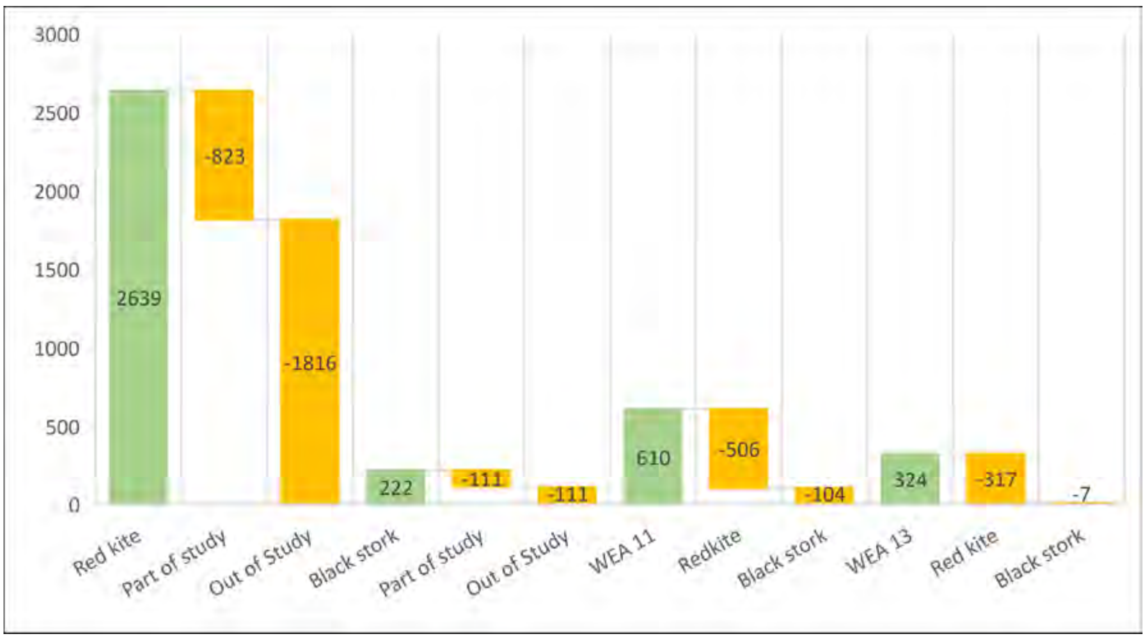


Figure 13 Illustration of LRF data (observation points) considered for evaluating acquisition rate

In the LRF data, each observation points belong to specific flight track of the targeted species. The number of species-specific tracks, with reference to collision risk zones at each wind turbines, under evaluation for acquisition rate are shown in the Figure 16. The tracks may have flights within different collision risk zones and therefore considered them in each zones of flight to calculate acquisition rate. While comparing the LRF data with recorded videos of the SafeWind system, matched videos of detection and/or regulation are identified within the duration of each track. Then, observation points within duration of matched videos are compared for flying direction, altitude and reference to landscape for declaring the confirmed acquisition of the track by the Safewind system. The results of the species-specific acquisition rate for red kite and black stork are presented as under:

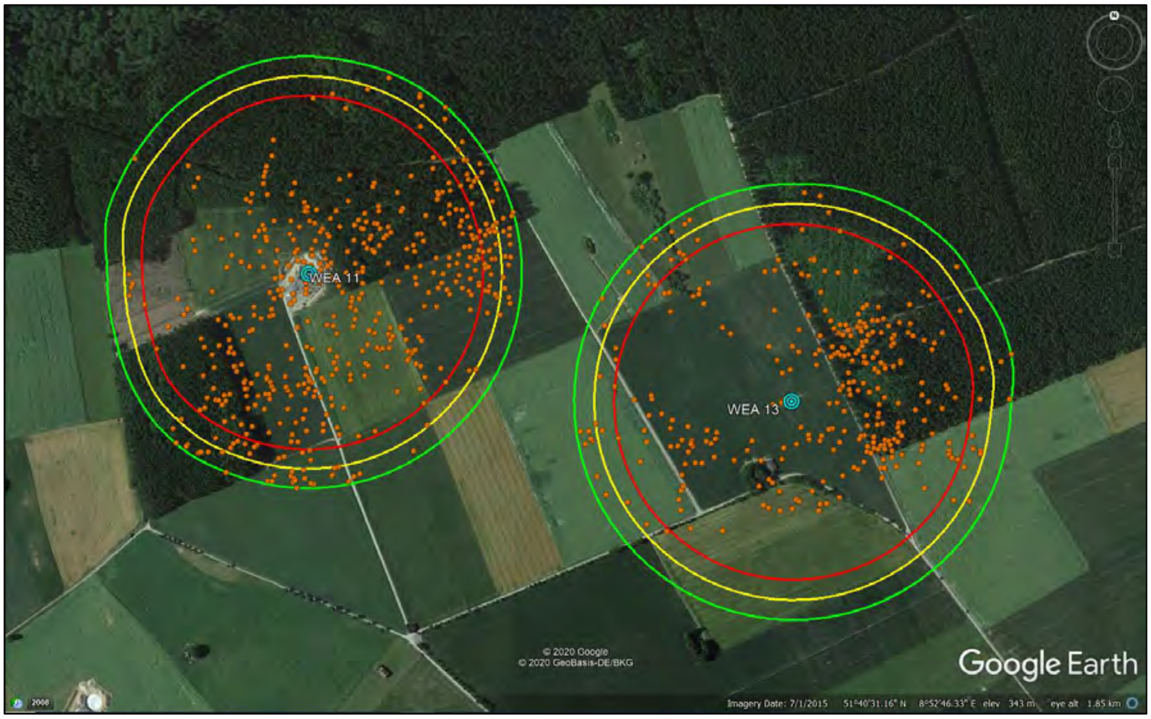


Figure 14 Observation points (orange points) of red kite around WEA 11 and WEA 13 (cyan circle – centre point) within detection ranges (red circle – 270 m, yellow circle – 300 m, green circle – 330 m)

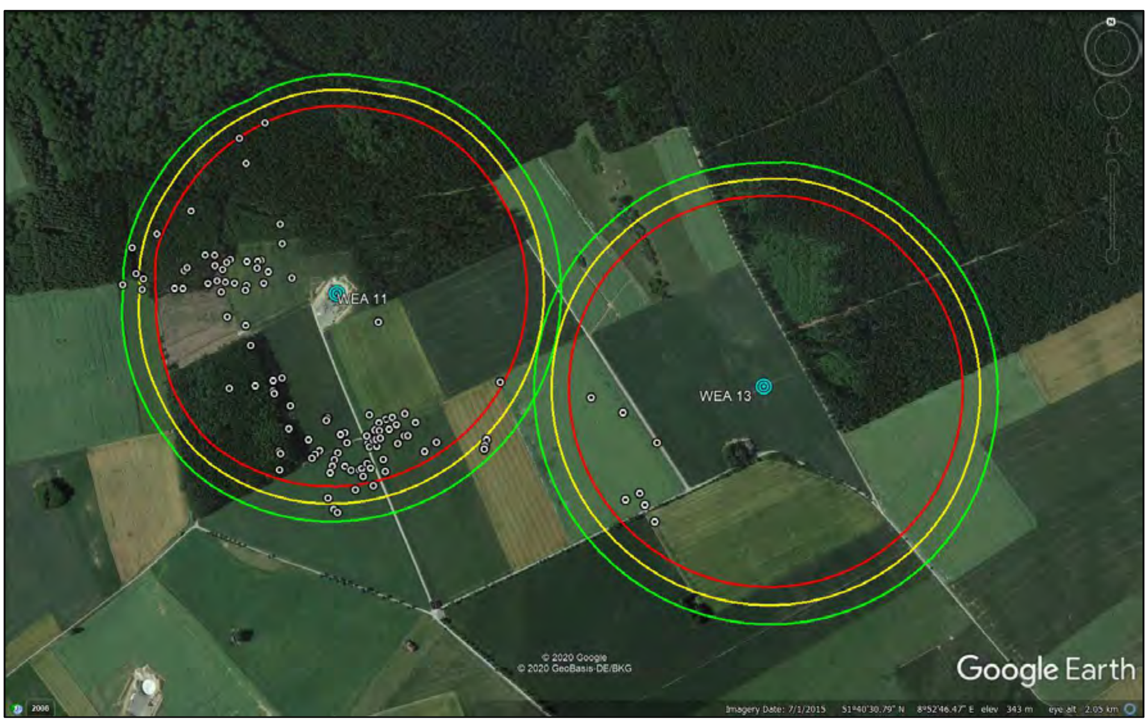
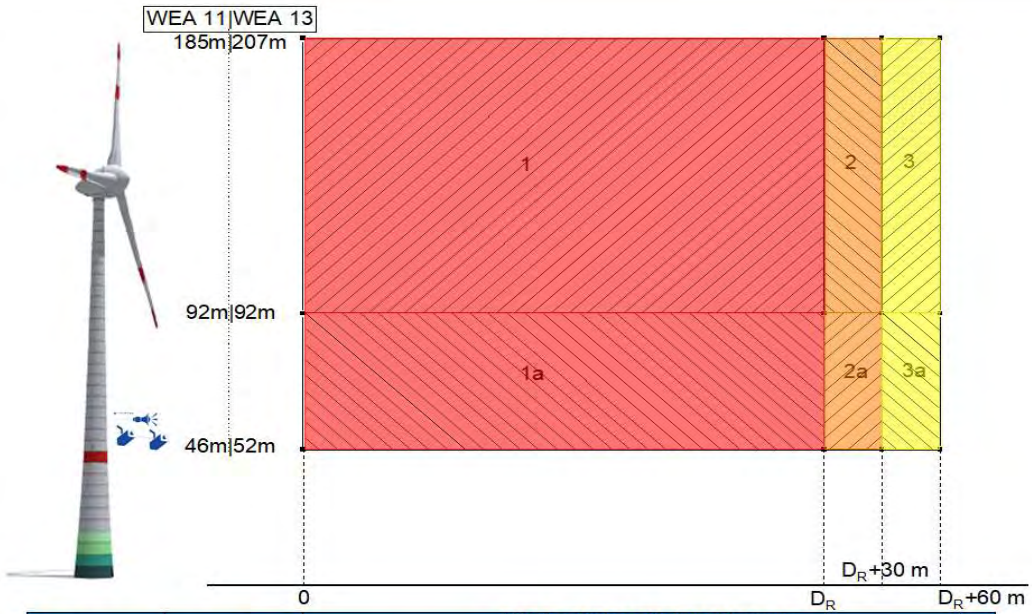


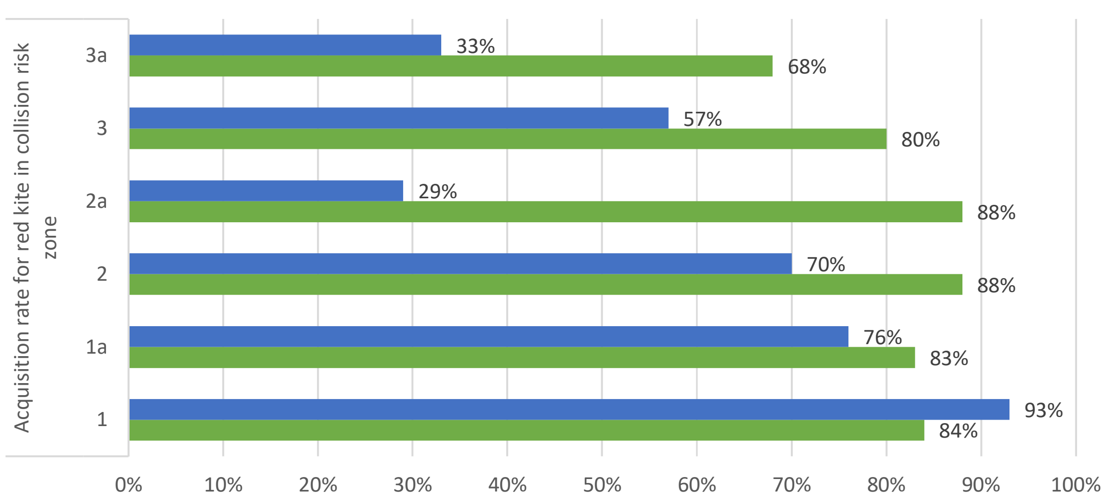
Figure 15 Observation points (white donut points) of black stork around WEA 11 and WEA 13 (cyan circle – centre point) within detection ranges (red circle – 337 m, yellow circle – 367 m, green circle – 397 m)



Bird Species	WEA	LRF tracks in collision risk zones					
		1	1a	2	2a	3	3a
Red kite	WEA 11	19	46	8	17	5	19
	WEA 13	15	25	10	7	7	6
Black stork	WEA 11	3	3	2	2	1	1
	WEA 13	1	1	0	0	0	0

Figure 16 Numbers of LRF tracks of red kite and black stork in collision risk zones for WEA 11 and WEA 13

4.2.2. Red kite



	Acquisition rate for red kite in collision risk zone					
	1	1a	2	2a	3	3a
WEA 13	93%	76%	70%	29%	57%	33%
WEA 11	84%	83%	88%	88%	80%	68%

Figure 17 Acquisition rate of SafeWind system for red kite at WEA 11 and WEA 13

The acquisition rate results as shown in figure 17 are presented as percentage of the flying tracks of red kite detected by the SafeWind system. The acquisition rates are shown for each collision risk zones and for each wind turbines. The acquisition rate of the SafeWind system in the collision risk zone 1 is maximum as 84% and 93% at WEA 11 and WEA 13 respectively. In case of collision risk zone 1a, SafeWind systems' acquisition rate is 83% at WEA 11 and 76% at WEA 13. For the collision risk zones of extended detection range (270 m - 300 m) in the rotor area, 2 and 2a, the acquisition rates are same as 88% at WEA 11, whereas, big variation between 2 and 2a at WEA 13, which are 70% and 29% respectively. The acquisition rate in the detection range 300 m – 330 m are reduced from previous zones at WEA 11, which are 80% for zone 3 and 68% for zone 3a. In case of zone 3, the acquisition rate is reduced from previous zone in the rotor area but is increased for zone 3a. They are 57% and 33% for zone 3 and 3a respectively at WEA 13.

Though the analysis of non-acquisition by the SafeWind system is not part of the study for the prototype installation, it is necessary to make hypothesis based on the learning outcomes for identifying possible areas of improvement. For visualization, all non-matching tracks of the LRF data for red kite are plotted in Google Earth as per Figure 18.

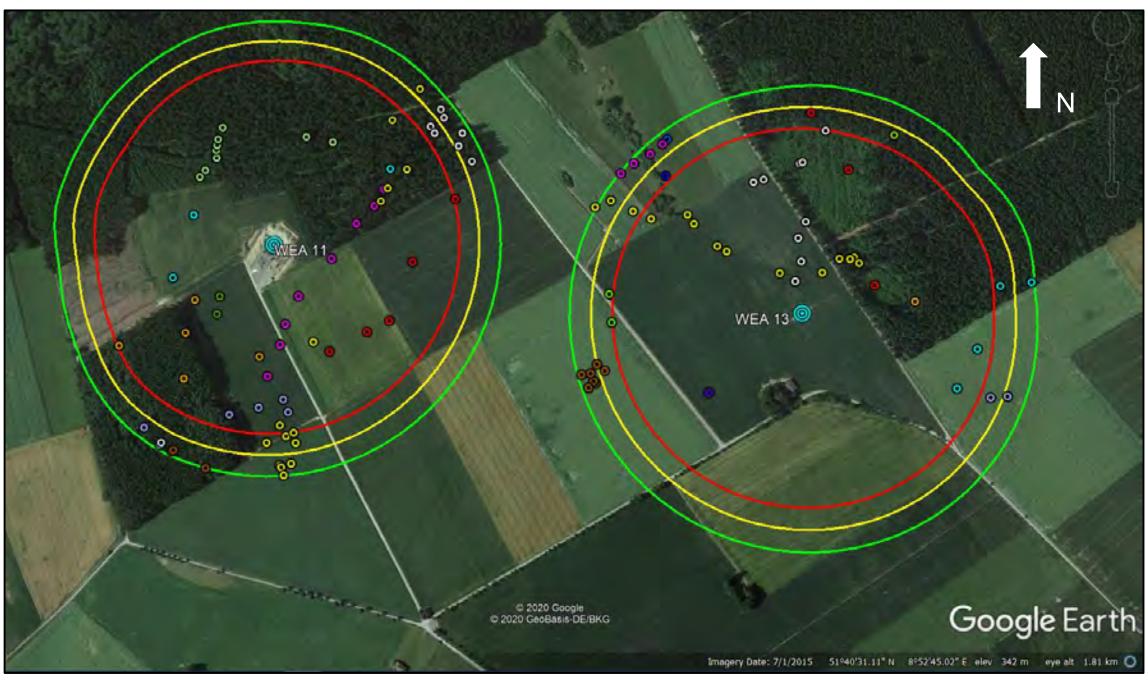


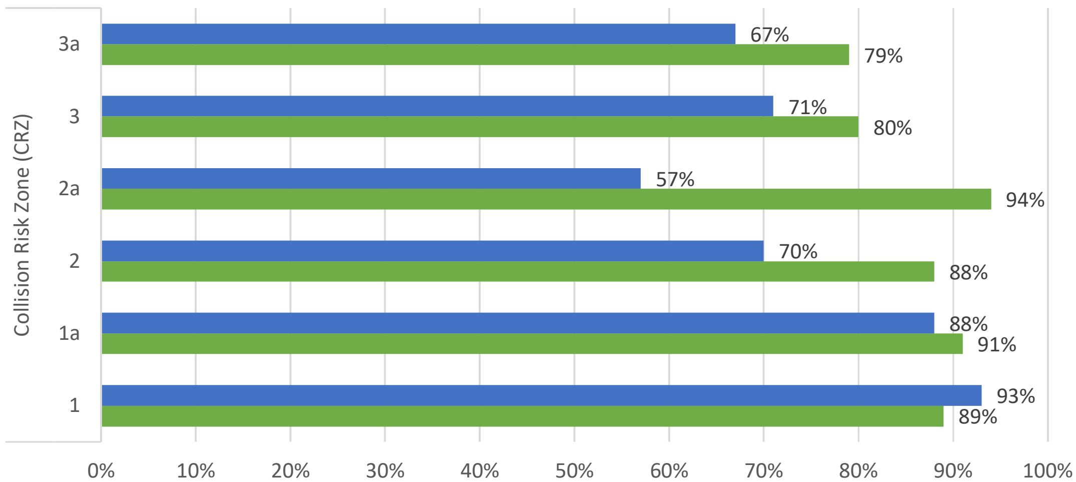
Figure 18 Non-matching tracks of red kite by SafeWind system

The results of Figure 17 show that the decrease of the acquisition rate vary between the wind turbines and is non-linear meaning that other factors than distance or position of bird may impact the detection capacity of the SafeWind system.

Topography is probably a factor to consider. Indeed, topography around WEA 11 has a slope, upward slope of approximately 15 m in northeast direction and downward slope of approximately 25 m in southwest direction at a distance of 200 m from wind turbine (GDI.NRW, 2020). Both the areas are covered with dark forest. The tracks flying above and/or before the dark forest and below the installation height of camera in southwest as well as northeast directions (tracks in Figure 18: orange, dark green, violet, pink, yellow) might be difficult to detect. Though the topography around WEA 13 is almost same but covered with dense dark forest from east to north until northwest directions (tracks in Figure 18: red, yellow, pink, white), hypothesis about lower altitude of flight and dark forest in background is also applicable at WEA 13. It might become more difficult, when weather is dark cloudy and field of view of camera has dark forest in the background. For easy understanding, comparison of sunny weather and dark cloudy weather from camera view for background forest are shown in Figure 19.

Figure 19 SafeWind camera view (upper window – sunny, lower window – dark cloudy)

Assuming that this hypothesis is addressed by Biodiv-Wind and tracks explained under hypothesis are detected by the SafeWind system, the increase in acquisition rates will be as per graphical representation in Figure 20.



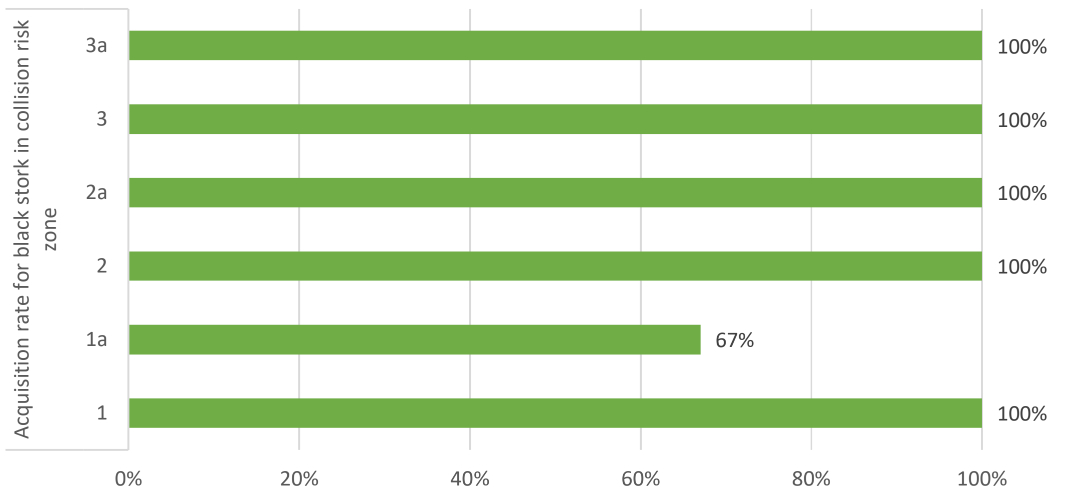
	Collision Risk Zone (CRZ)					
	1	1a	2	2a	3	3a
WEA 13	93%	88%	70%	57%	71%	67%
WEA 11	89%	91%	88%	94%	80%	79%

Figure 20 Acquisition rate of SafeWind system for red kite at WEA 11 and WEA 13 (based on hypothesis)

Second hypothesis is about correct reaction from the SafeWind system but without recording and/or transferring to the server. During analysis, it was found that the SafeWind system triggered shutdown control, shows 11s event log in SafeWind control system, and also confirms with SCADA status but no video was recorded. This could have found through the additional feature of the SafeWind system, which is continuous recording of camera with few weeks of buffer. However, the analysis of field data was performed too late and could not verify through continuous recording of camera.

4.2.3. Black Stork

The acquisition rate as shown in Figure 21 is presented as percentage of flying tracks of black stork from LRF data detected by the SafeWind system. The acquisition rates are shown for each collision risk zones at WEA 11. The acquisition rate of SafeWind system in all the collision risk zones is 100% except zone 1a, for which the result is 67%. At WEA 13, there is only one track in zone 1 and one track in zone 1a and both are not detected by the SafeWind system. Mathematically, the acquisition rate is 0% at WEA 13 for black stork.



	Acquisition rate for black stork in collision risk zone					
	1	1a	2	2a	3	3a
WEA 11	100%	67%	100%	100%	100%	100%

Figure 21 Acquisition rate of SafeWind system for black stork at WEA 11

As explained in case of red kite, non-matching tracks of LRF data for black stork are plotted as per Figure 22 to make the hypothesis. Hypothesis made for red kite are also applicable for black stork partly.

Figure 22 Non-matching tracks of black stork by SafeWind system (only for visualization)

4.3. Evaluation of collision risk probability

4.3.1. Input data

Whenever the SafeWind system triggers the shutdown control on wind turbine, Biodiv-Wind monitors the time required to reach to the pre-defined set points of blade tip speed. At WEA 11 and WEA 13, the durations are logged for two set points, 100 kmph and 50 kmph. Irrespective of bird species, all the shutdown logs of field observation dates are referenced for this report. The blade tip speed of 50 kmph corresponds to rotational speed of rotor as 2.88 RPM for WEA 11 (Enercon E-92) and 2.3 RPM for WEA 13 (Enercon E-115) which is assumed as safe rotational speed of the rotor to avoid the risk of collision. Figure 23 shows the box-whisker plot for time required to reach to 100 kmph and 50 kmph of speed of the rotor upon triggering of shutdown control from the SafeWind system. For calculation of the collision risk probability, maximum duration of 25.244 s for WEA 11 and 27.922 s for WEA 13 of the box-whisker plot are considered.

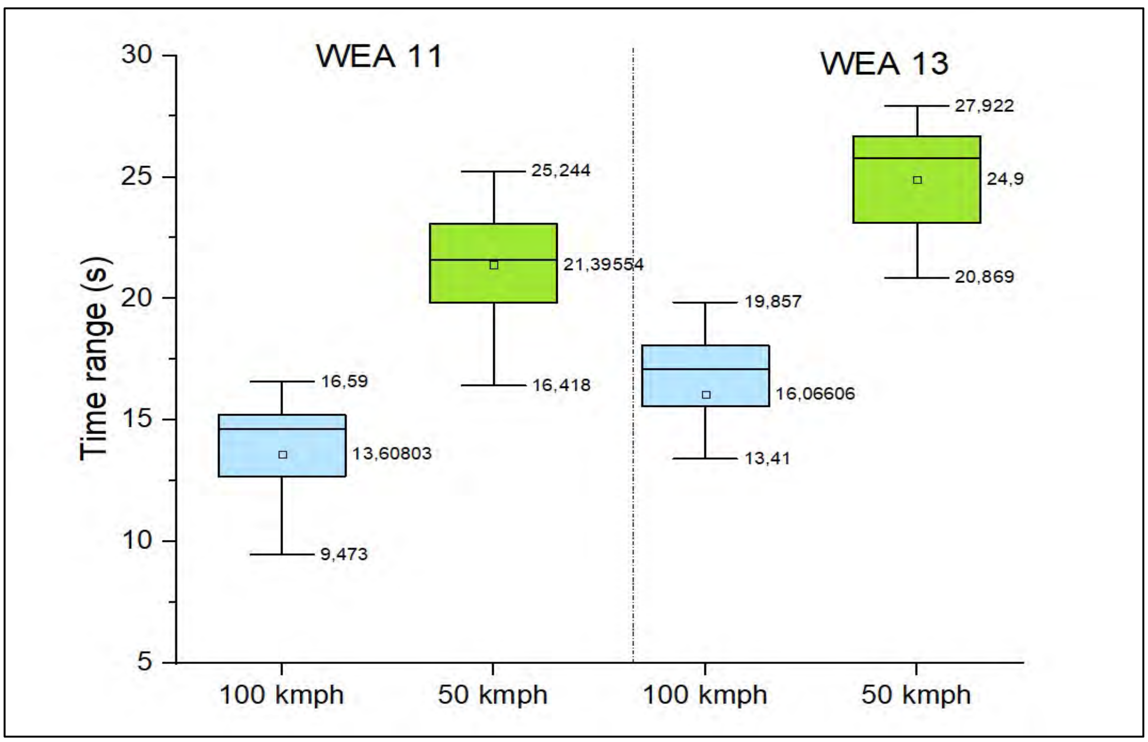


Figure 23 Box plot for time range in s to reach 100 kmph and 50 kmph blade tip speed for WEA 11 and WEA 13

4.3.2. Red kite

The reaction range for red kite is derived as 172 m from the Robird experiment. The average speed of each track of red kite flying within the reaction range of 172 m are considered from LRF data for determining the time required to reach to the rotor area. Figure 24 and Figure 25 show the result of each track as a graphical representation for WEA 11 and WEA 13 respectively.

For WEA 11, 3 tracks out of 33 tracks of the red kite within the reaction range of 172 m are reaching before the safe rotational speed of rotor resulting in to collision risk probability of 9%. In case of WEA 13, 3 tracks out of 25 tracks of the red kite within the reaction range of 172 m are reaching before the safe rotational speed of rotor resulting in to the collision risk probability of 12%.

Referring to the study on bird-vehicle collision, turkey vultures are able to anticipate the speed of moving object below 90 kmph (DeVault, 2014). Assuming linear interpolation between 100 kmph and 50 kmph tip speed of the blade, time required to reach to 90 kmph of tip speed of the blade are calculated as 18.32 s and 18.20 s for WEA 11 and WEA 13 respectively, upon triggering of the shutdown control. The collision risk probability reduces to 3% at WEA 11 and 8% at WEA 13 considering reference of the bird-vehicle collision study. Moreover, empirical data of Bird Sentinel[2] from Biodiv-Wind shows that collision events of red kite in France (n=7) and in Germany (n=1) appear only when blade tip speed is above 130 kmph. Considering this, the collision risk probability in our case is 0%. Certainly, there was no collision of any bird species during the entire duration of study.

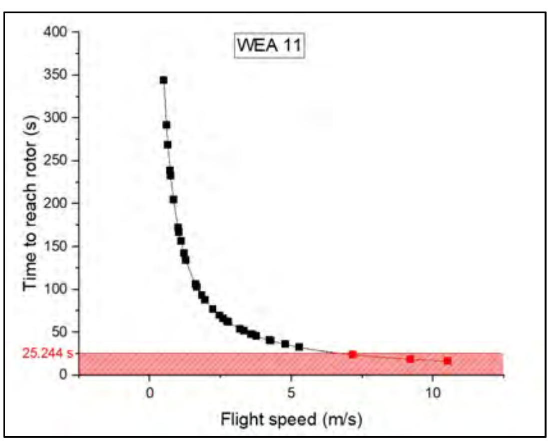


Figure 24 Time to reach rotor for each flight speed of red kite at WEA 11

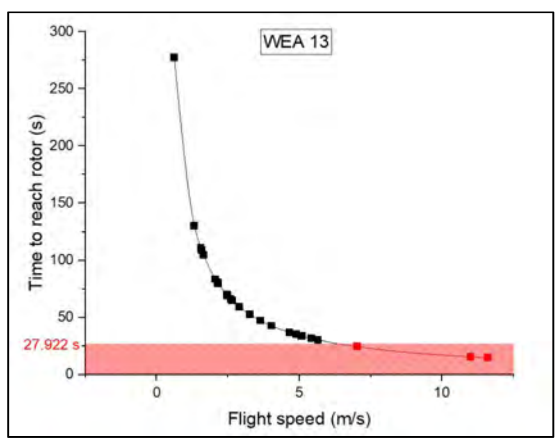


Figure 25 Time to reach rotor for each flight speed of red kite at WEA 13

2 Bird Sentinel is a system that records only the bird movements in the wind park.

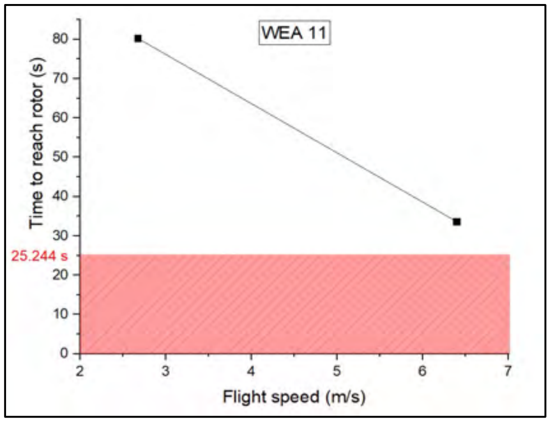


Figure 26 Time to reach rotor for each flight speed of black stork at WEA 11

4.3.3. Black Stork

The reaction range for black stork is derived as 215 m from the Robird experiment. The average speed of each track of black stork flying within the reaction range of 215 m are considered for determining the time required to reach to the rotor area. Figure 26 shows the result of each track as a graphical representation at WEA 11.

At WEA 11, none of the tracks of black stork within the reaction range of 215 m is reaching before the safe rotational speed of the rotor resulting in to the collision risk probability of 0%. In case of WEA 13, the collision risk probability is not calculated, as there is no track of the black stork within 215 m the reaction range.

5. Discussion

In this study, scientific base is created to decide on suitability of the SafeWind system for reducing the risk of collision of targeted bird species from the wind turbine. The SafeWind system shows 100% detectability for all simulated flights of the Robird drone. Estimated species-specific acquisition rates correspond with the detection range derived from the Robird drone experiment. It means that the maximum acquisition rate within the boundary of detection range (Figure 17) proves the reliability of the experiment, its data and derived results.

The study data for black stork (111 observation points), is limited for WEA 11 and inadequate for WEA 13 to make assessment. Therefore, results of the acquisition rate and the collision risk probability are to be either considered partially or supplemented with alternate study. For capturing higher observation points, one of the selection criteria for test location was presence of nest of the black stork in Marschetal area and study about flights of the black storks in Hassel wind park (NZO, 2017). The results can be recognized partially as wind turbines do not endanger the black storks (Finke, 2017). However, the alternate way would be to conduct the experiment of AVES series drone, which resembles black stork (AVES, 2020).

The SafeWind system achieves the maximum acquisition rates within the derived detection range. It is maximum 84% at WEA 11 and 93% at WEA 13 for red kite in the critical risk of collision considered as the rotor altitude (zone 1) within the detection range. Below the critical risk of collision (zone 1a) but within the detection range the acquisition rate shows 76% at WEA 11 and 83% at WEA 13 for red kite. In case of black stork, it is 100% and 67% at WEA 11. Therefore, the derived detection range from Robird experiment, 270 m for the red kite and 337 m for the black stork, can be stated as “safe detection range” (KNE, 2019).

Hypothesis on non-acquisition by the SafeWind system has brought important insight about the installation height of cameras on the wind turbine tower. At Hassel Wind Park, the un-used through holes for red aviation lights on wind turbine concrete tower were chosen for mounting of the camera at the respective wind turbines, 46 m on WEA 11 and 52 m on WEA 13. In such case, the low flying birds having dark background could have been missed by the camera due to obvious technical reason. Important parameters like topography around wind turbine, type of forests and their distance from the wind turbine, total height of the wind turbine and claimed detection range of the system for targeted species are to be studied during the feasibility stage of the project to define an optimum of installation height of the camera. With the optimized installation position of cameras that reduces the possibility of dark background, the acquisition rates can increase minimum of 5% more, when applied to the non-acquisition tracks (Figure 20) of the SafeWind system in all the collision risk zones in evaluation. Biodiv-Wind has broader prospects on improvement of the SafeWind system from the results and learnings earned from this evaluation. Interpretation of the hypothesis also indicates that the results of the evaluation of this report are transferrable to the installation of the SafeWind system in any geographical location, when parameters for the installation height of camera are studied in early stage of the project. Additional learning outcome from this hypothesis suggests that auxiliary continuous video recording must be used in parallel of real time detection during the assessment period, which will allow the objective analysis of so-called false negative.

A set point of the shutdown control in the SafeWind system derived as 172 m of reaction range for red kite from the Robird drone experiment. The worst-case scenarios, one that all red kite tracks fly at their average flight speed (Loske, 2020) directly towards the rotor area of the wind turbine from the distance of reaction range, and second its inability to anticipate the speed of moving object. In such cases, collision risk probability is determined as 9% at WEA 11 and 12% at WEA 13. These probabilities of risk of collisions are highly overestimated. The operation speeds of the rotor were found as close to the safe rotational speeds of the rotor for all the tracks of red kite estimated as risk of collision. This finding already eliminate the risk of collision of the tracks estimated. The biological avoidance behaviour of red kite is an important reduction factor for the estimated collision risk probability. However, the level of knowledge about the avoidance behaviour for the birds of prey is still insufficient in the field of ornithology (Consultant, 2016). In the absence of quantification of the avoidance behaviour, the anticipation behaviour plays an important role in defining the reduction factor. For the study of the SafeWind recorded videos, it has been clearly apparent that the red kite can anticipate the speed of the rotor and run through only when the rotor blade is passed. Referring to the study on bird-vehicle collision, it emphasise that such a birds of prey are able to anticipate the speed of moving object at less than 90 kmph (DeVault, 2014). Applying it to the overestimated collision risk probability, they are reduced to 3% at WEA 11 and 8% at WEA 13. Moreover, empirical data of Bird Sentinel from Biodiv-Wind shows that collision events of red kite in France (n=7) and in Germany (n=1) are recorded only when the blade tip speed is above 130 kmph. Considering this, the collision risk probability at Hassel Wind Park for both wind turbines, and with adopted threshold is 0%. In reality, there is no event of collision of red kite with the wind turbine.

Biodiv-Wind has kept the flexibility in setting of the parameters for detection and reaction independently. When activities of red kites or equivalent endangered species are increased in surroundings of the wind turbine, these parameters can also be increased. With the present settings and based on information from Biodiv-Wind, the average shutdown of the wind turbine can be approximately 10 minutes per day. Mathematically, when a radius of a hemisphere is increased by two-fold its volume is increased by eight-fold. Considering this, if the reaction range is set at double the distance from present the occasion of bird detection as well as the number of shutdowns of wind turbine may increase by eight-fold which can increase up to 80 minutes per day. Therefore, there must be an optimum balance on adjustment of the parameters.

The results of assessment on risk of collision and flexibility in the adjustment of the parameters authorize the conclusion that the SafeWind system is an effective measure for the bird protection from the wind turbines.

6. Literature

AVES. (25. June 2020). *The Drone Bird Company*. Von https://www.thedronebird.com/aves/ abgerufen

Consultant, B. (17. June 2016). *Ermittlung der Kollisionsraten von (Greif-)Vögeln und Schaffung planungsbezogener Grundlagen für die Prognose und Bewertung des Kollisionsrisikos durch Windenergieanlagen.* Von http://www.bioconsult-sh.de/site/assets/files/1561/1561-1.pdf abgerufen

DeVault, T. L. (February 2014). *Effects of Vehicle Speed on Flight Initiation by Turkey Vultures: Implications for Bird-Vehicle Collisions.* Von https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0087944&type=printable abgerufen

Finke, K. (13. April 2017). *Schwarzstörche bleiben Windrädern bei Paderborn fern*. Von Neue Westfälische: https://www.nw.de/lokal/kreis_paderborn/paderborn/21749391_Schwarzstoerche-bleiben-Windraedern-bei-Paderborn-fern.html abgerufen

GDI.NRW, G. I. (25. 06 2020). *GEOportal.NRW*. Von GEOportal.NRW: https://www.geoportal.nrw/ abgerufen

KNE. (2019). *KNE-Anforderungsprofil_an_eine_valide_Erprobung_von_technischen_Systemen_2019.* Von https://www.naturschutz-energiewende.de/wp-content/uploads/KNE-Anforderungsprofil_an_eine_valide_Erprobung_von_technischen_Systemen_2019.pdf abgerufen

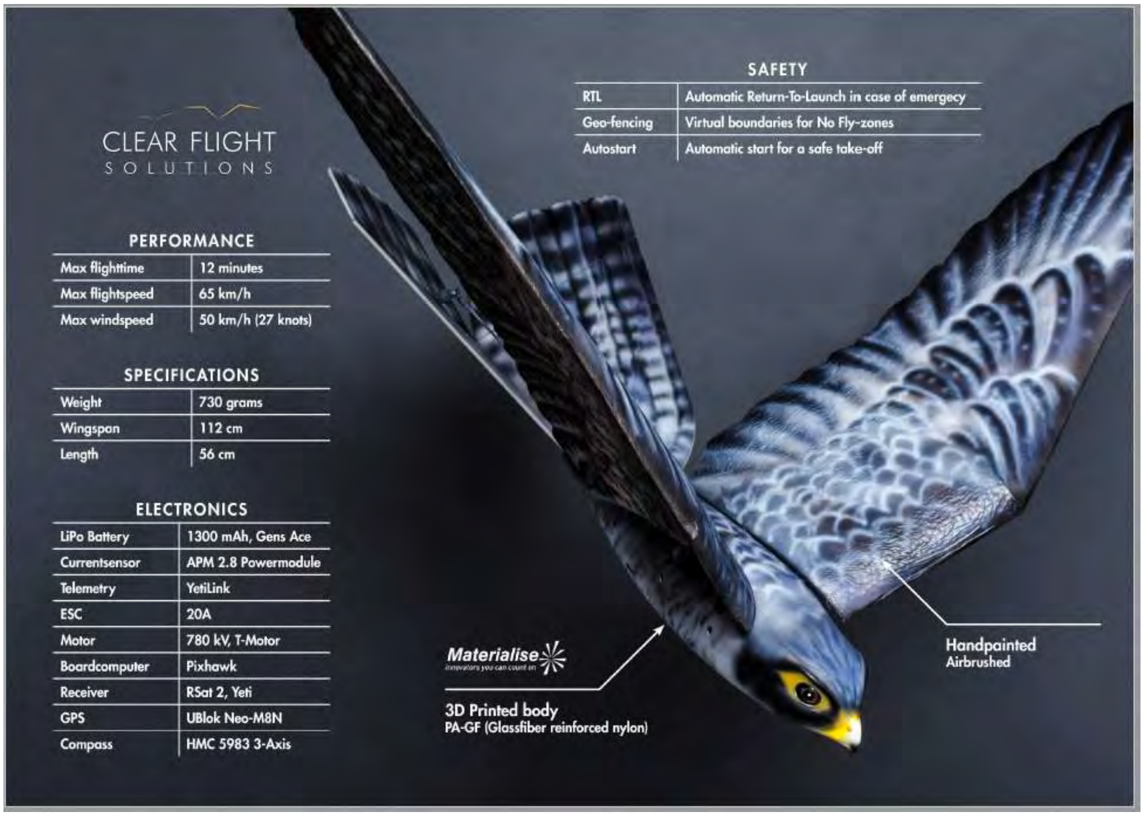
Loske. (2020). *Erfassung der Flugbewegungen von Rotmilan...* Salzkotten, Germany: Dr. Karl Heinz Loske.

NZO. (2017). *Untersuchungen zum Brutverlauf und zur Raumnutzung von Schwarzstörchen.* Bielefeld, Germany: NZO (Kreis Paderborn).

Wikipedia. (06. June 2020). *Haversine Formula*. Von https://en.wikipedia.org/wiki/Haversine_formula abgerufen

7. Annexures

I. Specification of the Robird drone



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