TORI DEFENDER

MONITORING AND MITIGATION SYSTEM FOR BIRDS AND BATS IN WIND ENERGY LANDSCAPES

POC AND TECHNICAL REPORT

BUCHAREST, JANUARY 2026

WILDERNESS RESEARCH AND CONSULTANCY

TORI DEFENDER SYSTEM FOR WIND TURBINES

Preserving Wings, Empowering Winds

Integrated Vision-Based Detection and Active Ultrasonic Deterrence System

POC and solution based comparison for the prototype

Wilderness Research and Consultancy
January 2026

12/8.1.2026

Ph.D. Dragoş Ştefan Măntoiu

Birds and Bats are often subject to impact at wind turbine installations, due to blade collisions, barotrauma (sudden pressure changes around the rotor swept area) or simple collisions with the towers especially in foggy periods. Bat fatalities registered at wind turbines represent the second biggest anthropogenic mortality factor recorded worldwide. Birds also have a high fatality rate, depending on the position and the migration pathways recorded locally. Most bat and bird species are protected by law worldwide (especially in Europe), so having a net zero fatality rate can ensure the sustainable and optimal functionality of a wind park, ensuring developers shareholders and creditors that the investment is solid and doets not pose a risk of operational shut down by the Environmental Protection Agencies or any legal action by wildlife conservation organizations. Reaching this net zero fatality rate has proven to be very technically difficult, but with accumulating knowledge on the fatality events and recent advancements in artificial intelligence, mitigation solutions have greatly improved during the last decade.

There have been many attempts to mitigate this impact, with early solutions ranging from direct human observers to acoustics or more advanced radar installations which shut down some wind turbines or the entire park in the migratory pathways. Carpet curtailment has also been used in cut in speeds of the turbines, for bats. The concept is simple and efficient and involves shutting down the turbines under a wind speed of 6.5 m/s (or lower, until 5 m/s), in sensitive periods, when bats are more active. Bats usually fly better in lower wind speed conditions, so the correlation has been very successful, but new wind turbines have a lower cut in speed, so the loss of production in these periods has proven to be very ineffective.

During the last 10 years, a new system has emerged, employing real time visual detection and artificial intelligence to shut down the turbines (blade feathering), only when an animal approaches the rotor swept area, with good results, both for bats and birds, but also for the efficiency of the energy production compared to other methods. Multiple cameras are deployed around the turbines, which feed the collected information within a local processing unit. Data processing is done in real time, calculating the trajectory of the objects and a decision is taken in the designated required time to feather the blades. Artificial intelligence is constantly trained by biologists, who manually identify animals for each shut down procedure, and confirm that the shutdown is valid or not, further increasing the system efficiency and decreasing false shut down procedures. Separate fatality field surveys are employed to check the effectiveness of the measures, but the system can also detect if a collision has occurred, sending teams on the field to investigate if necessary. Multiple add-on devices have been tested, with sound detection, but also with visual and acoustic deterrents, yet there still are huge challenges to tackle, as the system cannot predict the required shut down period for a day in advance, as required by most national electric transit networks, to reduce the power fluctuations in the market.

Recognizing the need for energy production predictability together with the net zero mortality rate for bats and birds, **Wilderness Research and Consultancy** is currently developing **TORI Defender**, a camera-based mitigation and acoustic deterrent system that considers the needs of the targeted species, while also predicting future movements based on the local activity and local migration pathways, to ensure a more integrated solution with the energy production needs, while abiding to the national and international environmental laws and agreements.

The solution is developed by biologists which have dedicated their careers to mitigating bat and bird mortality at wind parks, with the first successful measures implemented in Eastern Europe starting from 2011 and still in operation and monitoring to this day (Babadag Wind Park). The wind park reached net zero impact for two years in a row, after being the unit with the highest bat mortality recorded in Europe at that time, having a low implementation cost. Building up that knowledge and working together with artificial intelligence specialists, programmers and engineers, TORI Defender will ensure a better predictability of the movement of the animals compared to other existing solutions, based on new technological advances.

Existing solutions

Currently, several methods are used for mitigating fatalities at wind turbines:

- Radars – able to detect the presence and flight paths of airborne objects, including birds and bats, over long ranges
- Acoustic detections and shut down on demand for bats
- Cut-In speed Curtailments
- Human observers – traditional methods in which trained staff visually monitor bird activity
- Visual On demand Smart Curtailment Systems– which detect, track, and identify birds and bats in real time

Each of these methods has advantages and limitations. The following sections present the arguments supporting the idea that systems based on smart video cameras and AI are a superior solution to radar-based systems in terms of accuracy, adaptability, operational efficiency, and real protection of species.

Radars

Radars are systems that use electromagnetic waves to detect moving objects in the atmosphere, including birds and bats. They work by emitting radio waves that are reflected when they encounter an object, allowing estimation of its position, speed, and direction of movement. These systems can monitor bird movements over long distances and are particularly useful for detecting migration routes and bird fluxes at regional scale or in offshore areas. Depending on configuration, they can provide information on flight height and the density of bird traffic.

Acoustic detections

An effective method for detecting bats at wind turbines, with microphones installed in nacelles, towers or on the ground, and a central hub that automatically analysis the sounds and decides a turbine shut down if necessary.

Cut-In speed Curtailments (bats)

Cut in speed curtailment is a general method that reduces bat fatalities but rarely eliminates it due to its rigid approach and given the newly built turbines, it restricts energy production higher than ever before. Curtailment is usually raised to cut-in speeds of 5–6 m/s. European meta-analyses shows a 54–73% bat fatality reduction across 36–100+ turbines, with a pooled fatality ratio 0.37 (≈63% cut). Each 1 m/s increase in cut-in speed yields roughly +33% reduction, so typical 1.5–3 m/s Δ gives ≈50–62% reduction, especially for *Pipistrellus/Nyctalus*. When curtailment is focused on 2–6 h post-sunset peak window (≈70% of activity), effectiveness improves by ≈10–20% relative to all-night curtailment, while energy loss decreases.

Manual visual monitoring (human observers)

Human observers are a traditional monitoring method in which trained personnel (usually ornithologists or biologists) track bird or bat activity near turbines and make real-time operational decisions. This method is generally used in the short term, during impact study phases or in locations where technology is not yet available. It can be effective in identifying species and interpreting flight behaviour, but it has numerous limitations:

- It is very costly, requiring specialized staff, shift work, and permanent presence in the field.
- It is not scalable – difficult to apply in parks with dozens or hundreds of turbines.
- It does not allow automated reactions or systematic recording of data.

For these reasons, human observers are increasingly being replaced or complemented by automated technological solutions such as smart cameras or radars.

Optical and thermal cameras with artificial intelligence

Optical and thermal cameras combined with artificial intelligence (AI) algorithms represent cutting-edge technology for protecting birds and bats in wind farms. These systems operate by capturing real-time video images, based on which advanced visual recognition algorithms identify flying objects, determine their trajectory, and can classify species.

They are capable of accurately identifying protected species at distances of up to 1,500 meters. Detection is performed in the visible spectrum (daytime) and in infrared/thermal (nighttime or low-visibility conditions).

These cameras can be integrated into the turbine control system (SCADA) and can automatically generate commands to slow down or stop the turbine when a bird enters the risk zone, reducing collisions and energy losses.

- Camera systems with AI (MERLIN, DARC, **Tori – Wilderness Defender WRC** prototypes) detect bats in the **rotor swept zone (RSZ)** and issue **on-demand shutdowns**, replacing blanket cut-in strategies.
- Field studies indicate **70–91%** fatality reduction (site-specific ~80%+) with only **0.6–0.7% annual energy loss for the whole park**, outperforming pure cut-in (2–3.5% loss) in **"energy saved per bat saved"**.
- These systems cover **70–85% of the RSZ** and address **barotrauma risk** far beyond blade tips, which is crucial because a large number of fatalities are pressure-related, not blade strikes.

Advantages of optical solutions over acoustics

Acoustic solutions that sense bats and shut down turbines on demand offer well integrated systems, that collect, analyze and take decisions that are sent to the SCADA, but the coverage area of acoustic microphones is species specific and usually reaches 30-40 to 100 m detection (the latter limit is a best case scenario applicable only for *Nyctalus sp*. in optimal weather conditions). Most fatalities recorded show that bats usually die from barotrauma, which is a pressure difference area further away from the blade tips, thus increasing the kill radius of a rotor swept area. Most *Pipistrellus sp*. species do not emit further than 30-40 m (best case), and these species represent the main casualties at wind turbines. The time required for a controlled shutdown is usually at least 30 seconds, so the total response of such a device cannot optimally stop the turbine in due time. These solutions are potentially optimal for large scale migration, where there is a constant flux of animals, such as large colonies within the US, but their success rate may be limited in areas where migration is performed by smaller colonies, or where the animals choose to feed close to the nacelles of the turbines. There have been multiple cases documented in

Romania where bats wait for the turbines to shut down (wind speed curtailment), go to feed in the nacelle area, then descend under the rotor swept area and wait for another shutdown to feed in the desired area. If these behaviors are not mitigated, there is a risk of a longer shut down times than previously estimated. Nacelle acoustics sensors also have strong interferences from the operational noises generated by the turbines and may create false positives.

Although the solutions are more accessible than optical smart devices, they may increase the fatality rates significantly. Acoustic deterrents are an important component in all these systems (visual or acoustic) but may be subject to habituation in some instances and need to be managed. The existence of these devices will offer a path to efficient smart detection and prevention systems, creating a non-desirable area around the nacelles.

Advantages of optical solutions over radars

The following section presents a qualitative analysis of the advantages offered by camera-based monitoring systems. Several comparison criteria were considered for this analysis: accuracy of bird identification, visual confirmation, automatic turbine control, adaptability, operation under different terrain, light, and weather conditions, and flexibility.

Cameras integrated into AI systems can identify individual species with 94–99% accuracy, based on shape, size, and flight behaviour, and can calculate the trajectory of one or more individuals in real time. Radars, on the other hand, provide only a presence signal without details about species.

Cameras record video data that can be reviewed or used to improve existing models, increasing energy production efficiency and even predicting animal activity where sufficient data exist. Raw radar data must be processed and analysed, which may require specialized expertise.

Camera-based systems can reduce blade rotation speed or even stop the turbine as quickly as possible, but only when a protected species is detected in a risk area, reducing false shutdowns and energy losses. Radars cannot distinguish between a bird and an object, so they trigger shutdowns more often.

Modern models are equipped with thermal cameras that can operate at night and in difficult weather conditions while maintaining a high detection rate. Radars can be affected by rain or electromagnetic interference, becoming inefficient.

Cameras can be installed individually on each turbine or at strategic locations for detailed coverage of the area. Radar placement can be affected by rugged terrain, dense forests, or other obstacles that can create dead zones or impair detection accuracy.

Limitations of cameras

- Detection at very long distances (>1.5 km) is more difficult, especially for small or fast-flying birds.
- They require minimum visibility conditions.

These limitations can be offset by installing enough cameras and using complementary technologies (thermal cameras or a radar system), or in conjunction with carpet curtailments of cut in speeds for bats. Usually the impact during bad weather is lowered, especially for bats, as they are less active.

TORI Defender system

This system, currently under development in Romania by Wilderness Research and Consultancy, brings together over 15 years of experience gained in Romania and Eastern Europe regarding bird and bat movements at wind farms, using a set of stereoscopic cameras mounted at the base of towers and on nacelles, which can detect birds and bats with camera systems. In addition, the system will benefit from the FAR network, which will provide details on species in migration at 5, 10, and 15 km from the wind farm, through cameras, acoustic monitoring, and local microclimatic monitoring. With a sufficient volume of accumulated data, the system will predict the number of shutdowns for the following day, thus enabling fine-tuning of energy production in the grid.

Compared with radars, smart AI-enabled video cameras offer a much higher level of accuracy, adaptability, and operational efficiency for monitoring birds at wind turbines. Their ability to identify species, record video evidence, and automatically command turbine actions make them the ideal solution for the real protection of birds and for optimizing energy performance. Although radars may remain useful in offshore scenarios or for long-range detection, the camera + AI combination is currently the most complete and scalable solution available for bird protection in the wind energy context.

TORI Defender will feature the following features:

- Defender System – AI-based multi-camera detection and tracking, including static and PTZ cameras, with starlight technologies for adequate night monitoring
- Deterrent System – directional acoustic mitigation in sensitive areas
- FAT system – a set of cameras and ultrasonic microphones set at predefined locations alongside the migration pathways – as an optional training and early warning system

The system is designed to:

- Detect and classify flying objects in real-time
- Estimate collision risk based on trajectory analysis
- Actively reduce risk through targeted deterrence

Unlike radar-based systems, the proposed solution provides high-resolution classification, modular deployment, and significantly reduced cost, while maintaining real-time operational capability.

Limitations of Existing Solutions

Radar-based systems:

- High cost (€150,000–€300,000 per unit)
- High power consumption (~190–370 W)
- Limited classification accuracy (object type vs species-level inference)
- Complex installation and calibration

Passive monitoring systems:

- No real-time mitigation capability
- Limited operational value

SYSTEM ARCHITECTURE OVERVIEW

The proposed system consists of three integrated layers:

1. Detection Layer (Defender)

Multi-camera vision system for continuous monitoring

2. Processing Layer (Edge AI)

Real-time detection, tracking, and decision-making

3. Mitigation Layer (Deterrent)

Ultrasonic emission system for collision avoidance

DEFENDER SYSTEM – HARDWARE AND GEOMETRY

Camera Configuration: Each wind turbine is equipped with 4 modular units, each containing:

- **2 × Fixed Cameras (4mm lens)**
  - Resolution: 8 MP (4K)
  - Focal length: 4 mm
  - Low-light performance: STARLIGHT technology
- **1 × PTZ Camera**

  Model: IPC-HFW3541T-ZAS-27135
  - Resolution: 5 MP
  - Focal range: 2.7–13.5 mm
  - STARLIGHT technology

Total per Turbine

- 8 fixed cameras
- 4 PTZ cameras

Field of View and Coverage

Fixed Cameras (4mm lens):

- Horizontal FOV: ~87°
- Vertical FOV: ~46°

Detection Range:

- Large birds: up to 700–1000 m

- Medium birds and bats in contrast to the sky: 500–700 m
- Small birds and bats: up to 500 m

Module Coverage

Each module provides:

- ~120° effective coverage (including overlap)
- Redundant detection zones between adjacent modules

Global Coverage

- 4 modules placed at 90° intervals
- Full 360° cylindrical monitoring volume

Effective monitored volume:

- Radius: up to 1000 m
- Height: rotor swept area

4.5 Mounting System

- Magnetic mounting (Vestas-compatible)
- Secondary mechanical safety fixation
- No structural modification required

Installation Geometry

- Mounting height: 15–25 m from the ground
- Camera tilt: 5–15° upward
- Purpose:
    - maximize silhouette detection
    - reduce sky overexposure

PTZ Operation

- Default mode: continuous scanning pattern
- Trigger mode: lock-on tracking when object detected

EDGE AI PROCESSING SYSTEM

Hardware Platform

- NVIDIA Jetson Orin NX
- Optimized for edge AI inference

Detection Pipeline

1. Multi-camera video acquisition
2. Image preprocessing (resize, normalization)
3. Object detection using CNN (YOLOv8 architecture)
4. Object classification:
   - Bird
   - Bat
   - Noise / false positive

Performance Parameters

- Input resolution: 640 × 640
- Processing rate: 10–15 FPS per camera
- Detection latency: <100 ms
- Total decision latency: <300–500 ms

Multi-Camera Fusion

- Temporal synchronization between camera streams
- Spatial correlation of detections
- Cross-camera tracking for trajectory consistency

Distance Estimation

- Multi-view triangulation (approximate)
- Object size scaling
- PTZ-assisted depth estimation

COLLISION RISK ASSESSMENT

A risk score is computed for each detected object based on:

- Distance to rotor plane (d)
- Velocity vector (v)
- Angle of approach (θ)
- Time-to-impact (t)

Risk Model

Time-to-impact is computed assuming linear trajectory approximation within short time windows (0.5–2 seconds).
Rotor plane intersection is evaluated based on projected trajectory.

$$R = f(d, v, \theta, t)$$

Decision Logic

- Low risk → monitoring only
- Medium risk → tracking
- High risk → deterrent activation

DETERRENT SYSTEM – ULTRASONIC DESIGN

Hardware Configuration

- 4 × 4 ultrasonic and acoustic transducer matrix (16 elements)
- Frequency range: 1–120 kHz
- Sound pressure level: 110–130 dB
- **Ultrasonic deterrents** mounted on nacelles can reduce bat activity by **≈21–64%** and, in some trials, **>50%** for migratory species.
- When combined with traditional cut-in curtailment, some projects report **57–91% total reduction**, i.e., **26–82% additional** over curtailment alone.
- Deterrents are essential if **visual or acoustic on-demand curtailment** is used, because they **discourage bats from feeding near nacelles**, helping avoid **"shutdown loops"** where bats exploit repeated turbine stops. However, **habituation** has been observed and must be monitored and managed.

Acoustic Characteristics

- Beam angle: 30°–60°

- Directional emission
- Focused acoustic field

Effective Range

- Up to 60 m (directional)

Control Strategy

- Pulse modulation
- Duty cycle control
- Adaptive intensity based on risk level

Activation Logic

- Activated only when collision risk threshold is exceeded
- Minimize energy consumption and ecological disturbance

POWER SYSTEM

Power Consumption

Defender:

- Fixed cameras: ~64 W
- PTZ cameras: ~60 W
- Edge processing: ~25 W

Total Defender: ~150 W

Deterrent:

- Ultrasonic system: ~50–120 W

Total System:

~200–270 W per turbine

Power Supply

- 24V DC industrial supply
- Integration with turbine auxiliary power system

Protection

- Surge protection
- Grounding system
- Overcurrent protection

NETWORK AND DATA ARCHITECTURE

- Video protocol: RTSP
- Communication: Ethernet / PoE
- Processing: local (edge)
- Optional cloud integration:
    - event logging
    - analytics
    - reporting

ENVIRONMENTAL DESIGN

- IP rating: IP66 / IP67
- Operating temperature: -20°C to +50°C
- UV-resistant housing
- Anti-condensation system
- Vibration resistance

SYSTEM RESPONSE TIME

- Detection → classification: <100 ms
- Tracking + risk estimation: <300 ms
- Deterrent activation: <500 ms total

FAILURE MODES AND REDUNDANCY

- Camera failure → coverage ensured via overlap
- Edge system failure → monitoring fallback mode
- Deterrent failure → alert and logging only

COMPARISON WITH RADAR SYSTEMS

Radar systems provide robust detection in all weather conditions but at significantly higher cost and complexity. In contrast, the proposed system offers:

- Higher classification accuracy (vision-based AI)
- Lower cost and easier deployment
- Real-time mitigation capability

Radar-based systems typically consume up to ~370W and rely on signal interpretation rather than visual confirmation, while this system enables direct object recognition and behavior analysis.

DEPLOYMENT STRATEGY

- Modular installation
- Retrofit compatible
- Scalable across multiple turbines
- Suitable for large wind farms
- Installation time per turbine is estimated at 4–6 hours.

INNOVATION AND IMPACT

The system introduces:

- Real-time AI detection at edge level
- Active mitigation (not just monitoring)
- Cost reduction up to 90% vs radar systems
- Scalable architecture

SYSTEM LIMITATIONS

- Reduced performance in heavy fog / rain
- Small bird detection limited beyond ~100 m
- Ultrasonic effectiveness varies by species
- PTZ tracking dependent on initial detection

CONCLUSION

The TORI Defender System represents a practical and scalable solution for reducing bird and bat collisions in wind energy environments by integrating:

- Vision-based detection
- AI processing
- Ultrasonic deterrence

The system provides a technically robust, economically viable, and environmentally responsible solution.