Final Technical Report

Bat Smart Curtailment: Efficacy and Operational Testing

Federal agency to which the report is submitted: Department of Energy, Office of Energy Efficiency & Renewable Energy, Wind Energy Technologies Office (WETO)

Recipient: Natural Power **DUNS No.:** 0192561260000

Award Number: DE-EE0008900

Project Period: Budget Period 1

Principal Investigator: Jared Quillen, Ecologist, jaredq@naturalpower.com

Report Submitted by: Jared Quillen, Ecologist, jaredq@naturalpower.com

Date of Report: September 21, 2023

Working Partners:
Alliant Energy - Cedar Rapids, IA
Rizea Engineering – Steven Rizea, President

Cost Sharing Partners:
Alliant Energy - Cedar Rapids, IA
Renewable Energy Wildlife Research Fund - Washington, DC

DOE Project Team:
DOE HQ Project Officer – Nicholas Massey
DOE HQ Technical Project Officer – Raphael Tisch
DOE HQ Environmental Research Manager – Joy Page
DOE Field Contract Officer – Laura Merrick
DOE Field Grants Management Specialist – Stephanie Sites
DOE Field Project Monitor – Amy Sedlak

Acknowledgement: This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Wind Energy Technologies Office (WETO), Award Number DE-EE0008900.

Table of Contents

List of Figures

List of Tables

1 Executive Summary

Curtailment, or blanket curtailment, is a leading method to mitigate the impacts to bats from operating wind turbines. Although this strategy results in considerable decreases in bat fatalities, it also results in decreased energy production. In 2019, Natural Power was awarded funding by the Department of Energy to assess the readiness of the informed smart curtailment technology, EchoSense (formerly referred to as Detection and Active Response Curtailment, [DARC]). The research undertaken by this project expands the understanding of alternative methods, known as smart curtailment, to maintain a reduction in bat fatalities while simultaneously recovering lost energy associated with blanket curtailment. The overall project was composed of three major tasks; Task 1 was focused on cybersecurity compliance of the EchoSense system in accordance with the North American Electric Reliability Corporation Critical Infrastructure Protection ("NERC CIP") standards, Task 2 assessed the mechanical loads exerted on turbines when operating under a smart curtailment regime, and Task 3 assessed the efficacy of the EchoSense system at an operational wind farm.

Regarding Task 1, an external review by the National Renewable Energy Laboratory determined that the EchoSense system did not create any new cybersecurity weaknesses and was compliant with the NERC CIP standards. As a result of this process, Natural Power developed some best practices (10.1) for wind- wildlife technology developers. In conjunction with the National Renewable Energy Laboratory, the results (10.2) of the loads testing demonstrated that the periodic curtailment and release of turbines by the EchoSense system did not have any detrimental impact on the mechanical components of a wind turbine (Task 2). During the late summer to fall of 2020 and 2021, Natural Power demonstrated that the use of the EchoSense smart curtailment system resulted in no significant difference in bat fatalities compared to blanket curtailment with cut-in speeds at 6.9 m/s (2020) and 5.0 m/s (2021) while resulting in a significant difference in decreased lost energy (Task 3). This translates to an average of 41% (2020) and 56% (2021) reduction in per turbine energy loss compared to blanket curtailment. The reduction in energy loss that would have been achieved by EchoSense curtailment compared to blanket curtailment, if applied across all 69 turbines, is roughly equivalent to having an additional turbine on site. These results are notable for finding a balance between the environmental impact of wind energy and the economic feasibility in energy production associated with mitigating that impact.

2 Introduction

Many bat species in North America are under pressure from several external factors such as disease and anthropogenic effects. Wind turbines are sometimes linked with bat fatalities and can impact threatened or endangered species at the local and regional level. One easy way to reduce bat fatalities at wind farms is to stop the blades from spinning at night, especially during fall bat migration (typically August to October in North America). This method of mitigation is referred to as curtailment or blanket curtailment and it has been found to decrease bat fatalities up to 93% (Arnett et al. 2011). Much of the research into curtailment strategies involved testing different cut-in wind speed and the effects of those varying cut-in speeds on bat fatalities. The cut-in wind speed is the wind speed at which turbines start to rotate and produce electricity. To reduce the risk to federally listed bat species, the U.S. Fish and Wildlife Service (USFWS) recommends curtailment of turbines below a cut-in wind speed based on prior research. Typical cut-in wind speeds of 5.0 or 6.9 meters/second (“m/s”) are applied every night during the fall migratory period but can be extended to include the spring and summer months. This curtailment strategy can lead to considerable losses in energy production and provides no conservation value when bats are not present in the rotor swept area of wind turbines. Smart curtailment strategies have been tested as an alternative to blanket curtailment by only curtailing turbines when bats are present during periods of low wind speeds. One form of smart curtailment uses ultrasonic detectors to monitor for the echolocation calls of bats, and when combined with on-site weather data, selectively curtails turbines meeting specific thresholds in real-time.

In 2018, Natural Power proposed a three-part Bat Smart Curtailment (“BSC”) research project to assess the readiness of an informed smart curtailment technology. The Wind Energy Technologies Office awarded funding to validate the system and the project is part of the Department of Energy’s (“DOE”) ongoing support of technologies to mitigate wind-wildlife issues. The Renewable Energy Wildlife Research Fund also contributed to the effort. The overall project was broken into three major tasks with several subtasks. Task 1 was focused on the North American Electric Reliability Corporation Critical Infrastructure Protection cybersecurity compliance of the proposed BSC (formerly referred to as Detection and Active Response Curtailment, “DARC” now known as EchoSense) system. Task 2 assessed the mechanical loads exerted on turbines when operating under a smart curtailment regime. A test turbine was used in conjunction with the expertise of the National Renewable Energy Laboratory (“NREL”) to compare the various commands that can be used to stop the rotation of the blades for environmental curtailment. Task 3 involved the implementation of the EchoSense system at an operational wind farm. A suitable site was identified, and the system was instrumented on a subset of the total wind turbines in the project area. The wind farm was divided into three operational schemes to compare the effects of these curtailment strategies with regard to bat fatalities and lost energy production. This report summarizes the results of each task and stand-alone reports for each task are provided in the appendices.

3 Cybersecurity Compliance (Task 1)

Task 1 focused on cybersecurity compliance of the system. All organizations, including wind energy facilities, that support the Bulk Electric System are required to comply with a set of cybersecurity standards known as the North American Electric Reliability Corporation Critical Infrastructure Protection standards. NERC CIP defines the reliability requirements for planning, operating, and protecting the North American bulk power supply system including identifying and categorizing assets, implementing physical and digital security controls, and dealing with incidents and recovering from a cyber breach.

The addition and integration of third-party wind wildlife technology that creates new vulnerabilities within the NERC CIP cybersecurity envelope will not be accepted by potential wind energy operators. This may delay deployment on a large scale, prolonging the risk to the species that need protection provided by this technology (AWWI 2018). The most common third-party wind wildlife technology for reducing bat fatalities are smart curtailment and acoustic deterrents.

At the time of the proposal, Natural Power understood that clients would not adopt and implement a BSC system that did not meet their cybersecurity requirements. The expectation was that Natural Power and the EchoSense system would have significant responsibility for attaining and ensuring compliance with NERC CIP standards. However, as field deployment of the EchoSense system progressed, it became apparent that the Wind Farm Owner/Operator (“O/O”) would manage compliance for their systems and that Natural Power and the EchoSense system would help by providing details on the system installation, operation, and internal controls. This approach was confirmed by other wildlife technology developers and by Natural Power experience with commercial clients. In all cases the wind farm O/O vetted the existing cybersecurity protocols and practices of the EchoSense system to confirm that it did not create any new weakness or opportunity for intrusion. Final details on the integration of EchoSense with project network and cybersecurity protocols are often described in a network access or cybersecurity agreement. This agreement can also outline responsibilities for detecting and reporting any unusual activity or potential threats, as well as support and cooperation with any actions taken by the wind farm O/O to address threats and thwart attacks.

As our understanding of the technology providers’ cybersecurity roles and responsibilities evolved it was apparent that our original approach to task 1 and the scope was not in line with how the issue was being addressed. Therefore, Natural Power and the Department of Energy agreed that submittal of the final report [Appendix A] was a better approach for documenting wind farm O/O NERC CIP compliance expectations and lessons learned as a technology provider.

Planning for NERC CIP standards begins when the technology development process starts and continues for the life of the product. This long-term adherence to the standard requires flexibility from the technology developer as the NERC CIP standards evolve over the long lifecycle (>20 years) of a wind farm, as threats change, and as each client will interpret the NERC CIP standards from their unique perspective. We have seen examples of this, in which different clients perceive risks to certain approaches differently (e.g., use of cloud vs. on-site computing resources). So, despite calls for standardization, the continuing development of wind-wildlife technology along with legacy system integration, client preferences, and other variables will create challenges for technology providers and developers and likely require some level of customization for each system installation. Example requirements from technology users are in Table 3.1.

Table 3.1. Sample requirements from the technology purchaser.

Topic	Requirements	Discussion
Wildlife protection system data security	It shall be possible to secure the wind farm from external disruption of operation	Unless the Wind Wildlife technology is independent of the wind farm control systems, data security regulations or policies need to be observed by the Wind Wildlife technology, so that these do not pose a weak link in the defense against cyberattacks on the wind farm.
Reporting	It shall be possible to collect data for reporting	Reports may include events, duration, timing, source of attempt. An actual report may not need to be generated but the data for tracking these events needs to be generated, collected, and warehoused to implement continuous improvements and demonstrate compliance with regulations.
Alarms	It shall be possible to detect and highlight issues that require attention (e.g., numerous failed log-on attempts)	This creates a systematic and strategic process to respond to alarms. Focus efforts on issues that need to be addressed immediately (breach) and those that can be dealt with later (persistent but unsuccessful attacks).
Remote support	It shall be possible to get remote support for troubleshooting	Remote control will have data security implications and any kind of impact on the data security shall be documented.

Source: Adapted from The American Wind Wildlife Institute (AWWI). 2018. AWWI White Paper: Integration of Wildlife Detection and Deterrent Systems in Wind Power Plants. Washington, DC. Available at www.awwi.org. © 2018 American Wind Wildlife Institute.

Devices that integrate with the on-site network or Supervisory Control and Data Acquisition (“SCADA”) system or are otherwise behind the corporate firewall of the wind farm O/O will need to meet the cybersecurity expectations and requirements of the wind farm O/O. These will vary dramatically by wind farm O/O.

Some basic considerations:

- Depending on its design a system may require more or less cybersecurity. The device may reside exclusively external to the on-site or corporate network, or they may reside in the wind farms SCADA/plant controller. There are multiple layers of security. Penetrating more layers means more in-depth coordination between the technology provider and the end-user (AWWI 2018).
- These devices are likely to operate for years, maybe even the entire lifespan of the plant, including repowering.
- The cybersecurity threats are likely to change overtime (new sort of cyber-attacks).
- Devices may involve turbine curtailment, which require communication with the SCADA and/or in-turbine controls.
- To achieve the most reliable functionality at the plant or fleet level, there will need to be some level of integration between the external wildlife technology system and the wind power plant SCADA/control system (AWWI 2018).
- During the lifetime of the plant, there will be multiple revisions of the software applications for a subset of the systems of the plant. Reducing the effort related to restoring wildlife mitigation functionality after such upgrades is desirable. These upgrades may not be compatible (stop or interfere with) or may create unexpected operational actions by the wildlife technology.
- Due to security concerns, there will be increasing requirements and changing security protocols that protect the operation of the SCADA control system from unauthorized manipulation (AWWI 2018).

Through this process, Natural Power has distilled some best practices for wind-wildlife technology developers.

1. Integrate NERC CIP early and throughout the development. Plan for Defense-in-Depth.
    - Defense-in-Depth refers to a strategy the employs multiple security measures to protect a company’s resources. The core functionality is to provide additional layers of security as a backup to ensure malicious threats are stopped along the way. (Homeland Security External report: Control Systems Cyber Security: Defense in Depth Strategies, 2006)
    - Considering NERC CIP (and client specific) requirements from the start of the development process is critical but balanced so it can adapt to the requirements of the specific site or wind farm O/O. By considering NERC CIP at the start of the development stage, the process of integrating these third-party technologies into effectively operating wind farms can be streamlined and the end user will have a better experience using the new technology as an integrated part of their plant management strategy.
2. Understand how you plan to integrate into the wind farm O/O system.
    - The deeper the device resides in the site/corporate network, the more cyber awareness and practices may be needed.

3. Plan for the future of the system.
    - These devices are likely to operate for years, maybe even the entire lifespan of the plant, including repowering. Over this time the cybersecurity threats are likely to change overtime (new types of cyber-attacks).
4. Understand the trade-offs between integration and independence.
    - To get the most reliable functionality at the wind farm or fleet level, there will need to be some level of integration between the external wind-wildlife technology and the wind farm Supervisory Control and Data Acquisition (SCADA) system.

4 Integration with a Commercial Utility-scale Turbine (Task 2)

Task 2, entitled "BSC Integration with a commercial utility-scale turbine at the National Wind Technology Center," assessed the mechanical loads exerted on turbines when operating under a smart curtailment regime. The EchoSense system was integrated with the SCADA data collection system associated with a General Electric ("GE") turbine (Figure 4.1). Relevant loads and power data were collected over time. Analysis of this data demonstrated the loads and power effects of the EchoSense system on an individual utility-scale turbine.

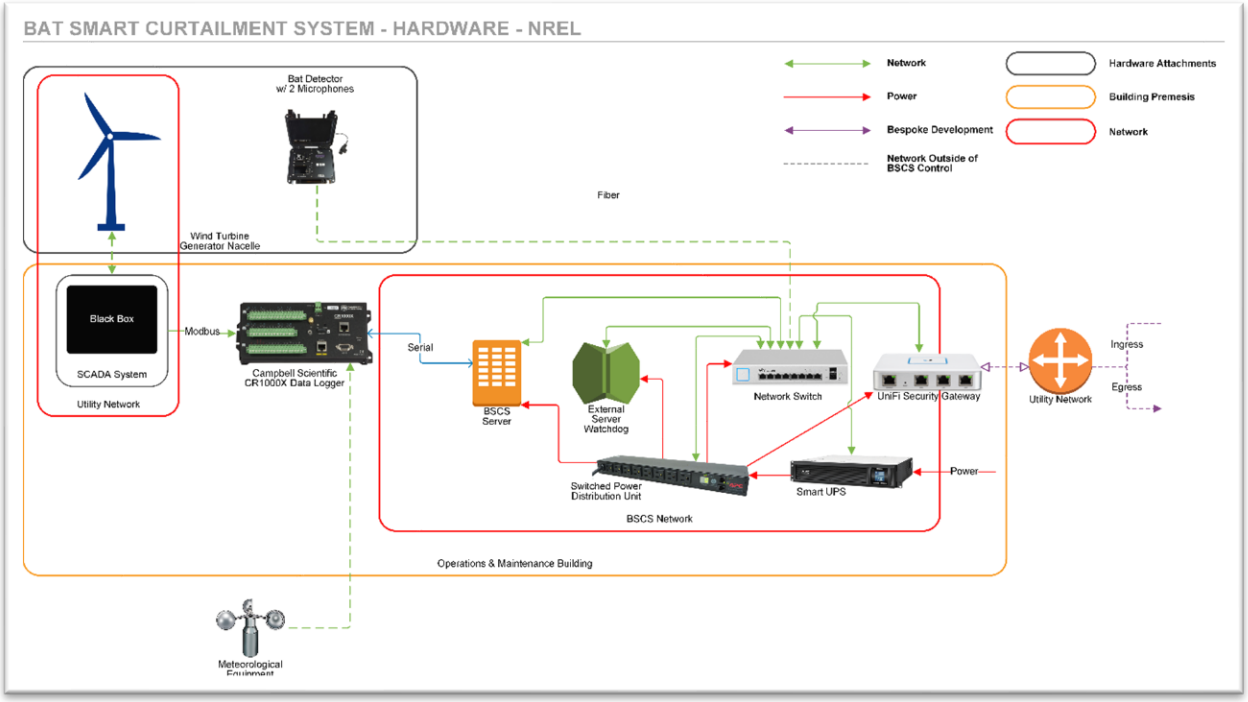


Figure 4.1. High-level overview of the EchoSense network.

A final test plan describing the scope of work was submitted to DOE on April 12, 2020. The test plan described the objectives, test procedure, and data collection criteria. In addition, the document provided details about the turbine, instrumentation, data acquisition, and the EchoSense system. This test campaign focused on curtailment response and mechanical loads measurements to assess any changes to component loads and fatigue life due to curtailment shutdown commands (tower bending and acceleration, main shaft bending and torque, as well as edgewise and flapwise bending moments) to assess any changes to component loads and fatigue life due to curtailment shutdown commands.

The data collection and analysis process followed guidance from the International Electrotechnical Commission's ("IEC") standard, Wind turbines – Part 13: Measurement of mechanical loads, IEC 61400-13, Edition 1.0, 2015, hereafter referred to as the Standard. The following is a summary of the results; the full results of the task 2 objectives can be found in Appendix B.

The test plan called for the field testing to be completed in approximately one month (March to early April 2020); however, the study encountered a series of hurdles caused by or exacerbated by the COVID-19 pandemic. The pandemic prevented NREL staff from being on-site at the Flatirons campus for many months, starting in March 2020 and continuing for the remainder of the year. This repeatedly delayed the testing and delayed detecting procedural errors (e.g., extended SCADA shutdown times), which necessitated repeating the testing process. Additionally, the Flatirons campus experienced a series of operational problems, including an extended shutdown and repair of the substation and maintenance of the GE test turbine, which further delayed the testing. The testing was finally completed in the Spring of 2021.

The Natural Power EchoSense system was evaluated on the NREL DOE GE 1.5 MW SLE wind turbine to determine loads impacts of a bat curtailment protocol. NREL engineers investigated shutdown options (Table 4.1) to meet the EchoSense requirements and determined two methods: 1.) Idle Command from the turbine user interface and 2.) Park Shutdown with a zero second power down ramp rate commanded from the Wind Plant controller. These two methods required user commanded prompts (not automated) when wind speed and turbine conditions were acceptable.

Table 4.1. Curtailment type descriptions.

Type	Turbine Power Response	Turbine Pitch Response	Responsiveness
0-sec Park Shutdown	Power ramp down in ~12-15 seconds	Blades pitch out	<2RPM in ~ 100-110 seconds
30-sec Park Shutdown	Power ramp down in ~30-40 seconds	Blades pitch out	<2RPM in ~120 seconds
MHI Idle Command Shutdown	Power cut out immediately	Blades pitch out immediately	<2RPM in ~60-70 seconds

Type	Turbine Power Response	Turbine Pitch Response	Responsiveness
MHI Stop Command Shutdown	Power ramp down in ~30-40 seconds	Blades not pitched instead HSS Brake applied once the rotor speed falls below a threshold	Similar to 30-second Park shut down but **not** advised due to negative impact of braking

Source: NREL

Over several months (July 22nd, 2020, to February 2nd, 2021), a database of turbine response due to curtailment (shutdown) commands was collected and subsequently processed for scaled engineering loads and further processed for fatigue by the method of rainflow cycle counting to determine short-term damage equivalent loads (“DEL”). The DEL results were compared with historical normal operation fatigue response (normal operation DELs) to determine the implications of curtailment on the fatigue life of the turbine under test.

Based on the curtailment process and fatigue analysis, it was determined that blade flap fatigue loads increase compared to the respective normal operation wind speed bin, but the edge fatigue is reduced, and for the cylindrical cross section of the blade root no increase in fatigue is experienced; fatigue results are below normal operation range. It was shown that flap fatigue loads increase due to idling gravity loads from pitching during shutdown. Meaning the cyclic gravity loading is shared between flap and edge directions as the blades change pitch angle to decelerate the rotor.

The main shaft was shown to have general reductions in fatigue loads when compared to normal operation. Similarly, the tower base displayed a reduction in fatigue loads on parity with normal operation DELs. Across load components, the Idle Command appears to have the most favorable response in terms of short-term fatigue and would be a preferable method for curtailment command for the turbine used in this demonstration. Overall, the fatigue loads associated with curtailment due to the EchoSense system do not have an adverse impact to the turbine when assessed using short-term DELs for the GE1.5 SLE turbine used in this study.

The results of this NREL-led loads study at the Flatirons campus suggest that undue mechanical stresses are absent when implementing the EchoSense system. The loads are within normal ranges and are not expected to increase stresses, reduce the life span, or otherwise be detrimental to the turbine’s mechanical systems. This work addresses a potential barrier to the broader adoption of the EchoSense bat smart curtailment system. A lifetime fatigue analysis is suggested to fully understand the turbine design life implications.

5 Efficacy of a Bat Smart Curtailment System (Task 3)

The purpose of Task 3 was to demonstrate successful implementation of the EchoSense system at an active wind farm during peak bat activity. Deployment at an operational wind farm permits evaluation of; 1) NERC-CIP readiness, 2) ease of integration/coordination with Original Equipment Manufacturer ("OEM") SCADA, 3) field worthiness and durability, and 4) efficacy in reducing bat fatalities while minimizing loss of energy production. Success was defined as reducing fatalities by 50% or more compared to normal operation at an annual energy production cost of at least 50% less than standard curtailment.

The first step in the field evaluation was to develop an Intellectual Property ("IP") management plan, which the Natural Power team members developed and executed. The plan described how members will handle intellectual property rights between themselves while ensuring compliance with Federal IP laws, regulations, and policies.

Alliant Energy/Interstate Power and Light Company as owner operator ("O/O") partnered with Natural Power and the English Farms Wind Farm was identified as a suitable test location. The O/O and Natural Power coordinated to develop a deployment and implementation plan. This plan addressed NERC-CIP readiness criteria, detailed requirements of communication with OEM SCADA (e.g., set point values), and physical location on hardware (e.g., servers and data loggers). This was used by the DOE to support a National Environmental Policy Act review of the test. The team drafted a study plan for the EchoSense testing which addressed: selection of instrumented turbines, selection of turbines for each treatment group, results of power analysis, fatality monitoring, EchoSense operational/risk decision rules, data collection/QA/QC, data management, and data analysis methods/approach.

The work was carried out at the English Farms Wind Project, owned by Alliant Energy, and located southeast of Montezuma, Iowa in Poweshiek County. This 170 MW facility comprises a total of 69 wind turbines including eleven 2.3 MW, 116-meter rotor diameter turbines and fifty-eight 2.5 MW, 127-meter rotor diameter turbines. Hub heights are 80 meters for 2.3 MW turbines and 88.6 meters for 2.5 MW turbines. The manufacturer's cut-in speed for both models is 3.0 m/s.

English Farms encompasses approximately 19,675 acres. The land is predominately composed of agricultural lands (cropland and hay/pasture). Cropland is dominated by corn and soybeans. There is a scattering of upland and riparian woodlots as well as open waterbodies (e.g., cattle ponds, streams).

The EchoSense system was installed at English Farms between July 20 and August 3, 2020, and remained in situ for the duration of the two-year study (microphones and sensors were replaced at start of 2021 season). The EchoSense system consisted of bat acoustic detection units which were installed on the nacelles of 5 turbines spread across the site (see Figure 3.2 in Section 3.3 of Appendix C) and a central server which communicated with the acoustic detectors and English Farm's SCADA system, installed at the substation (Figure 5.1). The detector microphones were mounted on the top rear of the nacelles at approximately 80-88 meters high. Acoustic detectors were placed independently of the treatments to which turbines were assigned (i.e., turbines with detectors were not necessarily operated under EchoSense control). Detectors were located at the edges of the site and were positioned to minimize the distance between any given turbine and a bat detector (Figure 3.2; Figure 3.3; Appendix C). The bat acoustic data collected at the 5 turbines was used in conjunction with meteorological and time data to determine whether the conditions for curtailment were met and if so, the curtailment action was sent out to all turbines operating under EchoSense control. EchoSense is a flexible system which allows the use of bespoke curtailment threshold and action settings. In this case, the system was set up so that one or more bat detections at any of the deployed detectors at a wind speed of less than 6.9 m/s (in 2020) or 5 m/s (in 2021) would trigger a 30-minute curtailment period across all turbines operated under EchoSense control. If no bat activity was detected during the final ten minutes of the curtailment period, turbines resumed normal operation. If bat activity was detected in the final ten minutes, the curtailment period was extended for a further ten minutes until a 10-minute curtailment increment was free from bat detections at which point normal operation would resume. Figure 5.2 provides an example of how the system operates.

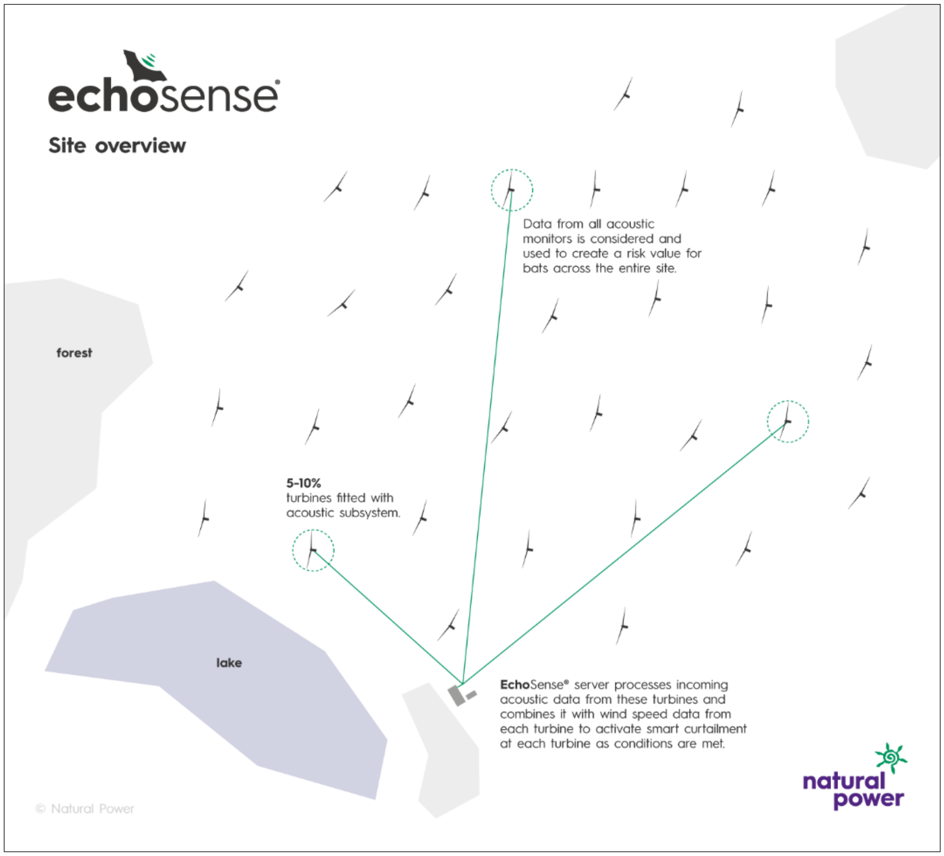
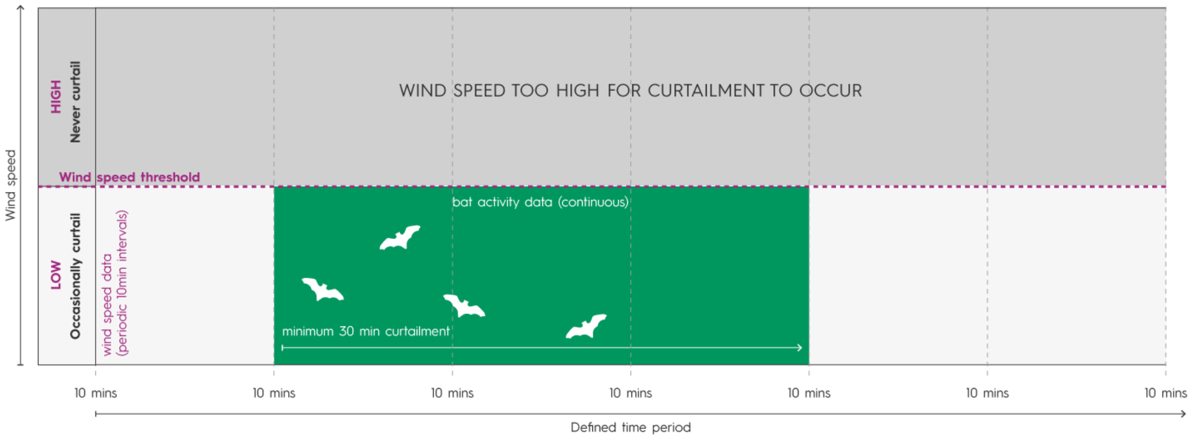


Figure 5.1. Example site layout.

A. Brief bat activity within defined wind speed and environmental parameters triggers minimum curtailment period of 30 mins



B. Sustained bat activity beyond 30 mins triggers ongoing curtailment in 10 min increments

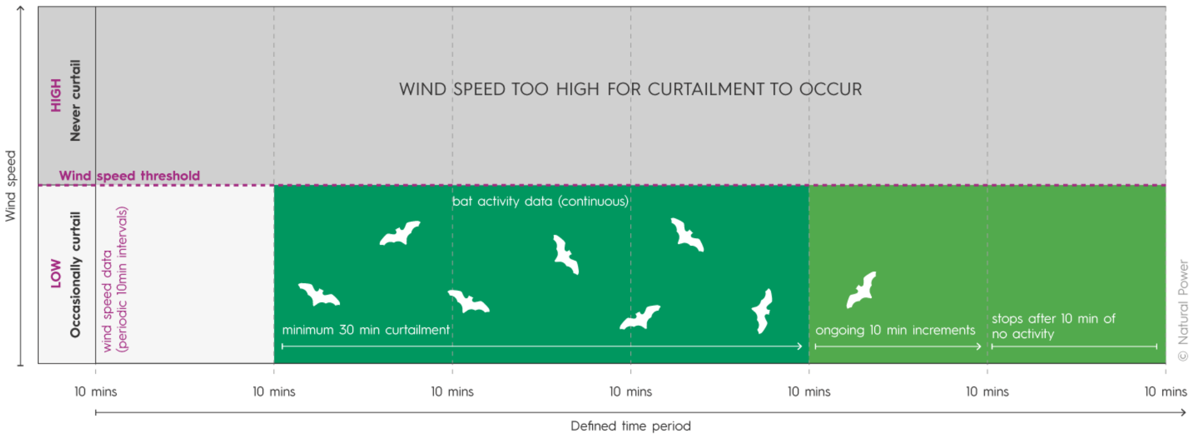


Figure 5.2. Example of the curtailment thresholds.

All 69 turbines were planned to be included in the study. Turbines were curtailed from Aug 4 to Oct 15 (80 nights) in 2020 and from Aug 4 to Oct 15 (80 nights) in 2021, within a nightly curtailment window of one-half hour before sunset to one-half hour after sunrise. This time corresponds to the period of maximum exposure and fatality for bats at English Farms (Alliant Energy, 2020) and the period during which curtailment is anticipated to be most effective as a long-term minimization strategy.

Two types of search plot were used at the study site: full plot, and road and pad. Full plots consisted of a 160-m square plot centered on the turbine bases in 2020 and a 120-m square plot centered on the turbine bases in 2021. Full plots were mowed once every 9 days immediately following a search to provide reasonable visibility throughout the study. During searches, searchers walked 6-m spaced transects covering the entire plot. This distance was chosen to ensure that surveyors would have good visual coverage over 100% of the area within the plot. In 2020, 28 turbines were surveyed according to the full plot methodology (25 of the 2.5 MW turbines and 4 of the 2.3 MW turbines). Three of the full plots were of reduced size (between 15% and 25% smaller) due to access restrictions. In 2021, 20 turbines were surveyed according to the full plot methodology (16 of the 2.5 MW turbines and 4 of the 2.3 MW turbines).

The remaining turbines (41 representing 34 of the 2.5 MW turbines and 7 of the 2.3 MW turbines in 2020 and 49 representing 42 of the 2.5 MW turbines and 7 of the 2.3 MW turbines in 2021) were surveyed according to the road and pad methodology. During road and pad searches, searchers walked along the edges of the roads and pads and scanned these areas for carcasses. Road and pad search plots extended further from the turbines than the full plots (160 m vs 60 – 80 m from the turbine tower), but a much smaller portion of the 160-m radius area was searched. Although these searches do not cover as great an area, they allow for investigation of fall distribution out to a greater distance and therefore estimation of the proportion of carcasses falling outside of the full plots.

It is important to note that in both years of the study, operational issues surrounding the turbine controls were encountered and our experimental design was implemented imperfectly. This was due to a mixture of issues including system configurations and communications with IT systems, software, and SCADA. Many of these issues were addressed as they were identified, and further refinement of protocols will be made to prevent these issues on subsequent projects using EchoSense. A key challenge of utilizing wind wildlife technology is the integration of third-party systems into the SCADA network and this was reinforced when trying to implement smart curtailment during this study. As part of the refinement process increased oversight of the software configuration and documentation are now included as part of system commissioning. The system now also includes automated error reporting, system diagnostics, and real-time dashboards with increased operator visibility. Additionally, the controlling software has been broken into independent services with the ability to auto-recover from failures and all software code is closely peer-reviewed and includes live debugging services.

One goal for this project was to demonstrate that the EchoSense system results in at least a 50% reduction in fatalities when compared to no minimization. The performance of both the EchoSense system and blanket curtailment were compared to a control in which turbine blades were feathered below 3.0 m/s during the first year of the study (2020). However, despite the assumption that blanket curtailment should reduce fatality rates by at least 28%, there was no statistical support that either treatment differed significantly from the control turbines (Figure 5.3).

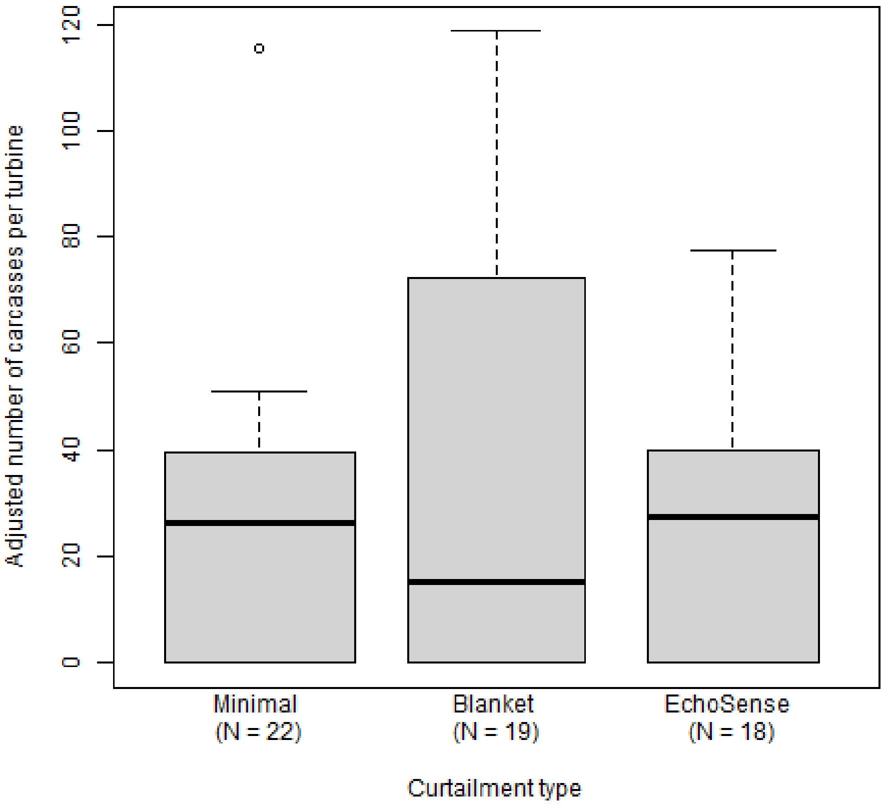


Figure 5.3. Number of bat carcasses detected per turbine in 2020 adjusted for detection probability and turbine operational time. The thick line indicates the median fatality rate, the box represents the interquartile range (IQR; within which 50% of the data are found) and the whiskers represent the quartiles ±1.5 * IQR. Points beyond the whiskers may be considered to be outliers.

This contrasts with numerous studies that have found that blanket curtailment significantly reduces fatality rates. In a meta-analysis of 19 studies conducted across 8 wind energy facilities with the majority in the U.S. (n=7), Whitby et al. (2021) found that total estimated bat fatalities are reduced by 33% for every 1.0 m/s increase in cut-in speed and at a 6.5 m/s cut-in speed, fatalities are reduced by an average of 79% (95% CI: 62-85%) when results are extrapolated across multiple facilities and years. In another meta-analysis of 36 studies conducted across 17 wind energy facilities throughout the U.S. and Canada, Adams et al. (2021) found strong evidence for fatality reduction by blanket curtailment, that is, there was an average of 63% (95% CI: 54-70%) decrease in fatalities across all treatments.

The lack of a statistically significant difference among treatments, especially in contrast to normal operation, could be explained if few bat collisions occur at wind speeds between 3 m/s and 6.9 m/s. At this site, pre-construction studies suggested that bat activity occurs at higher wind speeds than has been observed at most other wind farm sites, with 72% of activity occurring at wind speeds of above 6.9 m/s in 2013 (Appendix C of Task 3 Report) [PROTECTED]. Since bats are active at higher wind speeds at English Farms than elsewhere, it might also be that most collisions occur at higher (> 6.9 m/s) wind speeds when all turbines would have been operational. Intuitively, it is easy to imagine that collisions are proportionately more common for the same activity levels at higher wind speeds when flying conditions may be more difficult, but as wind speed covaries with bat activity (Weller and Baldwin, 2012), it is difficult to separate effects of wind speed and bat acoustic activity levels on fatality rates leading to a lack of available evidence to support this hypothesis. However, it is perhaps notable that in 2019 many bat fatalities (more than 1,700) were predicted to have occurred at the English Farms site despite all turbines operating under a blanket 6.9 m/s curtailment regime (Alliant Energy, 2020). Furthermore, the estimated rate of 10.26 bats/MW/year at the English Farms site is greater than the median rate (8.39 bats/MW/year) across the Midwest (AWWI 2020).

Another explanation for the lack of statistical difference among treatments could be a lack of statistical power. A statistical power analysis, an analysis used to calculate the probability of detecting a true underlying difference among treatments when accounting for study design and noise in the data, was carried out prior to the study. This analysis concluded that there was a 75% probability of being able to detect a difference among the control and the two treatment groups if there was a reduction in fatalities of at least 22% associated with either of the treatments (Appendix B of the Task 3 Report). However, statistical power was reduced by the fact that realized sample sizes were smaller, and the design less balanced than planned due to turbine operational failures. Indeed, a subsequent power analysis carried out for the realized experimental design suggested that the 28% reduction in fatality rate predicted to be associated with the curtailment treatments during the suitability analysis for the site would be detected with just a 44% probability (Appendix B of the Task 3 Report).

Increased power can be achieved by increasing sample size, but it can also be achieved by reducing noise (unexplained variation) in the data. Fatality rates predicted in this study were associated with large confidence intervals and this noise can mask underlying patterns in the data. In fatality studies, detection rates can be a large source of noise, with factors such as the effective area surveyed (based on density weighted proportion (“DWP”) and the proportion of carcasses found (determined by searcher efficiency and carcass persistence) playing a key role in the precision of estimates. Several measures could be implemented to reduce this effect including surveying more, and/or larger full plots (reducing uncertainty arising from DWP), conducting carcass searches more regularly (reducing uncertainty associated with carcass persistence) and increasing mowing frequency (maximizing searcher efficiency), as well as increasing the sample sizes used to determine correction factors. In this study, the study design was constrained by practical considerations. However, this has resulted in difficulty distinguishing a lack of effect versus a lack of statistical power.

During the second year of the study (2021), only two treatments were included: blanket curtailment and EchoSense curtailment, both applied at a 5 m/s cut-in wind speed. The reduction in treatments from three to two is associated with an increase in statistical power to detect differences among the treatments, because a greater number of turbines can be enrolled in each treatment. The lack of support for a difference among blanket curtailment and EchoSense curtailment in terms of bat fatality rate in 2021 suggests that at this site, EchoSense curtailment and blanket curtailment result in a similar bat fatality rate (Figure 5.4).

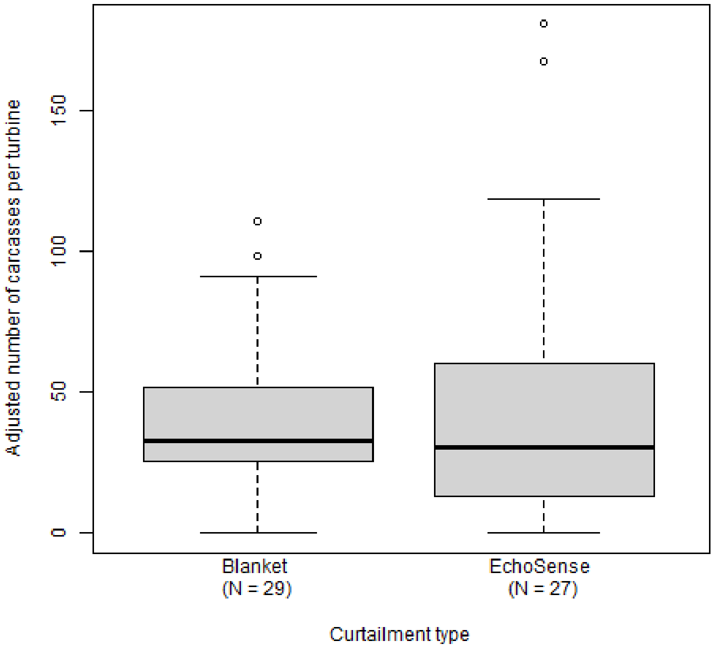


Figure 5.4. Number of bat carcasses detected per turbine in 2021 adjusted for detection probability and turbine operational time. The thick line indicates the median fatality rate, the box represents the interquartile range (IQR; within which 50% of the data are found) and the whiskers represent the quartiles ±1.5 * IQR. Points beyond the whiskers may be considered to be outliers.

The second goal of the study was to demonstrate that the EchoSense system results in at least a 50% reduction in energy loss when compared to blanket curtailment at the same wind speed cut-in. The suitability analysis carried out for the site, prior to implementation, suggested that blanket curtailment at a 6.9 m/s cut-in would result in an AEP (Annual Energy Production) loss of between 1.1 and 1.6% while the EchoSense system should result in a loss of around 0.1%. However, in this study, curtailment loss associated with blanket curtailment was 2.1% (6.9 m/s cut-in) and 0.5 % (5.0 m/s cut-in) while curtailment loss associated with EchoSense curtailment was 1.2% and 0.2% for the 2020 and 2021 studies, respectively. See Figure 5.5 for the 2020 results and Figure 5.6 for the 2021 results.

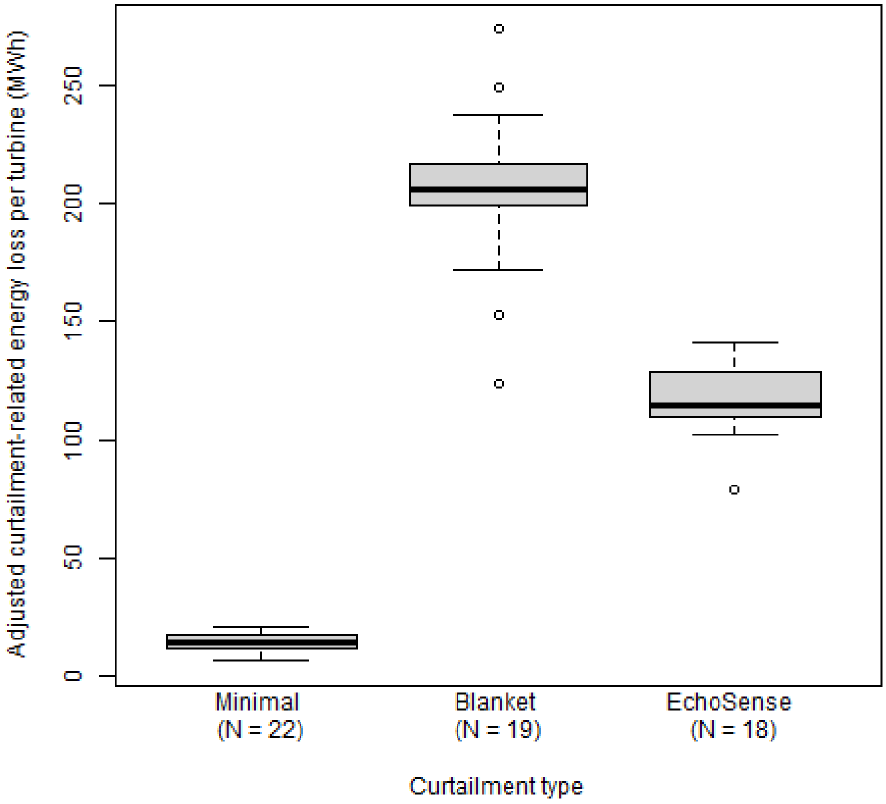


Figure 5.5. Predicted curtailment-related energy loss per turbine in 2020 adjusted for turbine operational time. The thick line indicates the median energy loss, the box represents the interquartile range (IQR; within which 50% of the data are found) and the whiskers represent the quartiles ±1.5 * IQR. Points beyond the whiskers may be considered to be outliers.

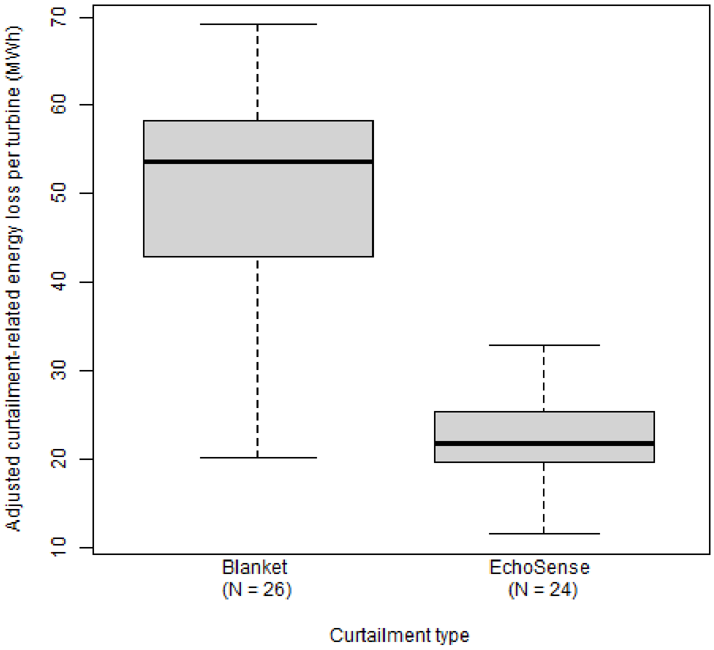


Figure 5.6. Predicted curtailment-related energy loss per turbine in 2021 adjusted for turbine operational time. The thick line indicates the median energy loss, the box represents the interquartile range (IQR; within which 50% of the data are found) and the whiskers represent the quartiles ±1.5 * IQR.

The difference in pre-construction estimates versus real-world estimates can be attributed, in small part, to the fact that the suitability analysis was carried out assuming no curtailment rather than the final control regime (3.0 m/s) used in this study. However, a more significant factor which likely contributed to this discrepancy is wake and hysteresis effects. These calculations were based on a methodology which did not include wake effects on measured wind speeds or hysteresis (the effect of recent events on the status of the system). Not considering wake effects in the suitability analysis curtailment loss estimates means that the estimates were based on a free-stream wind speed, resulting in higher wind speeds in the suitability assessment and therefore less time below cut-in. Additionally, curtailment was observed above the specified cut-in wind speeds by amounts as much as 0.6 m/s. This is due to a combination of hysteresis effects and SCADA control implementation considerations which cannot be quantified in the suitability assessment without assessing real world operations of the curtailment strategies. These are now incorporated as standard in suitability analysis calculations carried out by Natural Power prior to implementation of the EchoSense system.

EchoSense curtailment represented a reduction in energy loss of 41% compared to blanket curtailment at 6.9 m/s (year one) and a 56% reduction compared to blanket curtailment at 5.0 m/s (year two). The reduction in energy loss by approximately 5,490 MWh that would have been achieved by EchoSense curtailment compared to blanket curtailment at a 6.9 m/s cut-in speed is roughly equivalent to having an additional turbine on site, if applied across all 69 turbines. The 1,684 MWh reduction in energy loss that would have been achieved by EchoSense curtailment compared to blanket curtailment at a 5.0 m/s cut-in speed also represents a significant increase in energy production across all turbines. In addition to the reduced energy losses, the variability of losses within the EchoSense curtailment treatment group were significantly lower than the blanket curtailment treatment groups (Figure 5.6, $X^2 = 393.84$, $p < 0.001$). The reduced variability lowers the associated energy uncertainty and could therefore reduce the spread of probability of exceedance cases in pre-construction energy estimates. This reduction in uncertainty in conjunction with the almost 1% recovery of per turbine energy loss between the blanket (2.13%) versus EchoSense (1.24%) minimization strategies in the 2020 study and 0.3% energy recovery in the 2021 study is financially meaningful and could make the difference between an economically viable and unviable project.

6 Conclusion

Evaluation of the efficacy of bat smart curtailment is an important area of research to conserve bats while minimizing energy loss associated with standard blanket curtailment strategies. It is also important to address operational concerns that are barriers to industry acceptance of bat smart curtailment such as cybersecurity compliance and turbine load changes. This DOE funded study into these issues should help to reduce these barriers and give operators more confidence in the integration of informed smart curtailment systems such as EchoSense.

Task 1 focused on cybersecurity compliance of the system and sought to identify and address any weaknesses and gaps in current security practices. With the support of NREL experts, the network security protocols employed within the EchoSense system were evaluated and minor adjustments were made to the system architecture. Additional vetting of the system cybersecurity was conducted by a wind farm operator in preparation for the operational efficacy part of this study (task 3). The evaluation by both parties concluded the cybersecurity practices employed by Natural Power and EchoSense meet the NERC-CIP policies that govern wind farm operations. As result of this process, Natural Power developed some best practices for wind-wildlife technology developers.

The task 2 objective was to focus on curtailment response and turbine mechanical loads measurements to assess any changes to component loads and fatigue life because of curtailment shutdown commands. With the support of the NREL team, a well instrumented test turbine was outfitted with the EchoSense hardware and various curtailment methods were evaluated with particular attention paid to the mechanical stresses that may be part of a smart curtailment regime. The results of this study at the Flatirons campus suggest that undue mechanical stresses are absent when implementing the EchoSense system. The loads are within normal ranges and are not expected to increase stresses, reduce the life span, or otherwise be detrimental to the turbine's mechanical systems.

The goals of task 3 were to demonstrate at least a 50% decrease in bat fatalities associated with EchoSense turbines as compared to control turbines, and a 50% reduction in energy loss associated with EchoSense turbines as compared to the blanket curtailed turbines. These goals were not met in the first year of the study due to technical issues (41% reduction in energy loss in 2020), but the EchoSense system did achieve a reduction in energy loss of greater than 50% in the second year of the study (56% in 2021). The EchoSense smart curtailment system was able to considerably reduce lost energy (1,684-5,490 MWh) associated with curtailment for bats compared to a blanket curtailment system and would thereby provide substantial economic benefits over blanket curtailment at the site. The study also found no evidence that the rate of bat fatalities associated with EchoSense turbines differed to that associated with blanket curtailment when applied at the same cut-in wind speed at this site (fatality reduction: 2020 blanket [$\bar{x}$ = 33.92, 90% CI: 31.32, 36.51] vs. ES [$\bar{x}$ = 28.94, 90% CI: 27.04, 30.83], 2021 blanket [$\bar{x}$ = 40.05, 90% CI: 38.67, 41.42] vs. ES [$\bar{x}$ = 47.18, 90% CI: 44.86, 49.50]). Further studies will be required to confirm the generality of these findings. While not within the scope of this test, future studies can benefit from the lessons learned in this deployment including detailed predictive modeling approaches which should include treatments for wakes, hysteresis, and plant availability. Further operational integration issues such as turbine control integration protocols and overall system reliability can impact the results, especially for wind farms that have significant downtime due to reliability issues.

7 References

Adams, E.M., Gulka, J. and K.A. Williams. 2021. A review of the effectiveness of operational curtailment for reducing bat fatalities at terrestrial wind farms in North America. PloS one, 16(11), p.e0256382.

Alliant Energy. 2020. Post-construction small bird and bat mortality survey report. English Farms Wind Energy Facility. Project No. 117095. Version 2.0.

American Wind Wildlife Institute (AWWI). 2020. AWWI Technical Report: 2nd Edition: Summary of Bat Fatality Monitoring Data Contained in AWWIC. Washington, DC.

American Wind Wildlife Institute (AWWI). 2018. AWWI White Paper: Integration of Wildlife Detection and Deterrent Systems in Wind Power Plants. Washington, DC. Available at www.awwi.org. 2018 American Wind Wildlife Institute. Prepared By Kaj Skov Nielsen, Independent Consultant

Arnett, E. B., M. M. P. Huso, M. R. Schirmacher, and J. P. Hayes. 2011. Changing wind turbine cut-in speed reduces bat fatalities at wind facilities. Frontiers in Ecology and the Environment 9(4): 209–214; doi:10.1890/100103 (published online 1 November 2010).

Homeland Security External Report # INL/EXT-06-11478, Contol Systems Cyber Security: Defense in Depth Strategies, Prepared by Idaho National Laboratory, May 2006. Recommended Practice: Defense-in-Depth (energy.gov)

International Electrotechnical Commission's (IEC) standard, Wind turbines – Part 13: Measurement of mechanical loads, IEC 61400-13, Edition 1.0, 2015

Whitby, M.D., M.R. Schirmacher, and W.F. Frick. 2021. The state of the science on operational minimization to reduce bat fatality at wind energy facilities. A report submitted to the National Renewable Energy Laboratory. Bat Conservation International. Austin, Texas.

8 Technology Advancement

The Natural Power EchoSense system is commercially available. The first commercial sale occurred in 2021 with two more commercial installations occurring in 2022. For 2023, EchoSense is operating at three commercial installations with nearly 700 MW under EchoSense control.

9 Dissemination

The status and results from this award have been presented at the following conferences and webinars.

Quillen, C.J., G. Vallejo, D. Saywers, R. Rodriguez, and K. Denman. 2022. Balancing Bat Conservation and Renewable Energy Production with EchoSense. The 29th annual conference for The Wildlife Society, Spokane, Washington.

Quillen, C.J. 2022. Balancing Bat Conservation with Renewable Energy Production. The 19th International Bat Research Conference / 50th North American Symposium for Bat Research, Austin, Texas.

Quillen, CJ. 2022. Balancing Bat Conservation with Renewable Energy Production. American Clean Power Siting and Environmental Compliance Conference 2022, Round Rock, Texas.

Rodriguez, R., G. Vallejo, D. Saywers, J. Quillen, and K. Denman. 2022. Balancing bat conservation and wind energy production with EchoSense. 14th Wind Wildlife Research Meeting, hosted by the Renewable Energy Wildlife Institute, Kansas City, Missouri.

Rodriguez, R., J. Quillen, G. Vallejo, D. Saywers, and K. Denman. 2023. Implementing a Smart Curtailment System to Reduce Bat Fatalities and Energy Loss at Wind Energy Facilities. Northeast Bat Working Group Meeting, Burlington, Vermont.

Rodriguez, R., J. Quillen, G. Vallejo, D. Saywers, and K. Denman. 2023. Recovering Energy Loss at Wind Energy Facilities using the EchoSense Smart Curtailment System. American Clean Power Siting and Environmental Compliance Conference, Albuquerque, New Mexico.

Rodriguez, R., J. Quillen, G. Vallejo, D. Saywers, and K. Denman. 2023. Implementing a Smart Curtailment System to Reduce Bat Fatalities and Energy Loss at Wind Energy Facilities. Western Bat Working Group Meeting, Victoria, British Columbia.

10 Appendices

10.1 Appendix A – Task 1: Cybersecurity Compliance Final Report

EchoSense Task 1 Final Report

DOE Award (DE-EE0008900)

11 April 2022

DOE

US Department of Energy

Document history

Author	Jared Quillen, Ecologist	21 March 2022
Checked	Jared Quillen, Ecologist	11 April 2022
Approved	Kevin Denman	11 April 2022

Client Details	
Contact	Joy Page
Client Name	US Department of Energy
Address	Golden Field Office

Issue	Date	Revision Details
A	1 March 2022	First Draft
B	25 March 2022	Response to DOE comments
C	11 April 2022	Final Issue

Local Office:

Saratoga Springs, NY 12866
USA

Registered Office:

Saratoga Springs, NY 12866
USA

Contents

Task 1 report

Federal agency to which the report is submitted: Department of Energy, Office of Energy Efficiency & Renewable Energy, Wind Energy Technologies Office (WETO)

Recipient: Natural Power DUNS 0192561260000

Award Number: DE-EE0008900

Project Title: Bat Smart Curtailment: Efficacy and Operational Testing

Project Period: Budget Period 1

Principal Investigator: Jared Quillen, Ecologist, jaredq@naturalpower.com

Report Submitted by: Jared Quillen, Ecologist, jaredq@naturalpower.com

Date of report: April 11, 2022

Working Partners:

Rizea Engineering – Steven Rizea, President

NREL - National Renewable Energy Laboratory

Cost Sharing Partners:

None

DOE Project Team

DOE HQ Project Officer – Nicholas Massey

DOE HQ Technical Project Officer – Raphael Tisch

DOE HQ Environmental Research Manager – Joy Page

DOE Field Contract Officer – Laura Merrick

DOE Field Grants Management Specialist – Stephanie Sites

DOE Field Project Monitor – Amy Sedlak

Acknowledgement: This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Wind energy Technologies Office (WETO), Award Number DE-EE0008900

1. Executive Summary

This document is intended to aid all stakeholders who develop or utilize third party technologies to address wind energy impacts on wildlife. Most wildlife technology is developed by third parties, except for the wildlife-specific controls that are offered by some turbine manufactures. Integrating these third-party technologies at a wind farm has the potential to create new cybersecurity vulnerabilities for the wind farm and the larger grid. This paper provides background on the relevant regulations, standards and best practices when considering such integration.

Natural Power has identified the following as practices for Wind Wildlife technology developers.

1. Integrate the North American Electric Reliability Corporation Critical Infrastructure Protection ("NERC CIP") early and throughout the development. Plan for Defense-in-depth.
    a. Considering NERC CIP (and client specific) requirements from the start of the development process is critical but balanced so it can adapt to the requirements of the specific site or wind farm Owner/Operator ("O/O"). By considering NERC CIP at the start of the development stage, the process of integrating these third-party technologies into effectively operating wind farms can be streamlined and the end user will have a better experience using the new technology as an integrated part of their plant management strategy.
2. Understand how you plan to integrate the Wind Wildlife device into the wind farm O/O system.
    a. Wind farms have multiple layers of security. The deeper the device resides in the site/corporate network, the greater the requirements for cyber awareness, implementation of best practices and coordination between the technology provider and the end-user.
3. Plan for the future of the system.
    a. These devices are likely to operate for years, maybe even the entire lifespan of the wind farm, including repowering. Over this time the cybersecurity threats are likely to change to account for diverse types of cyber-attacks.
    b. During the lifetime of the wind farm there will be multiple revisions of the software applications for a subset of the systems of the wind farm. Reducing the effort related to restoring wildlife minimization functionality after such upgrades is desirable. These upgrades may interfere with (or stop) the operation of the Wind Wildlife technology.

    The upgrades may also trigger unexpected or unwanted actions by the Wind Wildlife technology.

4. Understand the trade-offs between integration and independence.
    a. To get the most reliable functionality at the wind farm or fleet level, there will need to be some level of integration between the external Wind Wildlife technology and the wind farm SCADA/control system.
5. Retain flexibility and capability to respond.
    a. Due to security concerns, there will be increasing requirements and changing security protocols that protect the operation of the SCADA control system from unauthorized manipulation.

2. Introduction

This document is intended to aid all stakeholders who develop or utilized third part technologies to address wind impacts on wildlife. Most wildlife technology is developed by third parties, except for the wildlife-specific controls that are offered by some turbine manufactures. Integrating these third-party technologies at a wind farm has the potential to create new cybersecurity vulnerabilities for the wind farm and the larger grid. This paper provides background on the relevant regulations, standards and best practices when considering such integration.

All organizations, including wind energy facilities, which support the Bulk Electric System (“BES”) are required to comply with a set of cybersecurity standards known as the North American Electric Reliability Corporation Critical Infrastructure Protection standards. NERC CIP defines the reliability requirements for planning, operating, and protecting the North American bulk power supply system. It covers everything from identifying and categorizing assets, to implementing physical and digital security controls, to dealing with incidents and recovering from a cyber breach.

The addition and integration of third-party wind wildlife technology that creates new vulnerabilities within the NERC CIP cybersecurity envelope will not be accepted by potential wind energy operators. This may delay deployment on a large scale, prolonging the risk to the species that need protection provided by this technology (AWWI 2018). The most common third-party wind wildlife technology for reducing bat fatalities are smart curtailment and acoustic deterrents. Smart curtailment systems use real-time or predicted exposure rates of bat activity to determine when to curtail turbines to maximize the conservation of bats while minimizing the effect on renewable power production. Acoustic deterrents use ultrasound signal(s) to deter bats from entering the high-risk airspace around the rotor.

In 2018, Natural Power proposed a three-part Bat Smart Curtailment (“BSC”) research project. Task 1 was focused on NERC cybersecurity compliance of the proposed BSC (formerly known as Detection and Active Response Curtailment, “DARC”) system now referred to as EchoSense.

Task 2 assessed the mechanical loads exerted on turbines when operating under a smart curtailment regime. Task 3 was the implementation of the BSC system at an operational wind farm. At the time of the proposal Natural Power understood that clients would not adopt and implement a BSC system that did not meet their cybersecurity requirements. The expectation was that Natural Power and the EchoSense system would have significant responsibility for attaining and ensuring compliance with NERC CIP standards. However, as field deployment of the EchoSense system progressed, it became apparent that the Wind Farm Owner/Operator (O/O") would manage compliance for their systems and that Natural Power and the EchoSense system would help by providing information about its product. This approach was confirmed by other wildlife technology developers and by Natural Power experience with commercial clients. In all cases the wind farm O/O vetted the existing cybersecurity protocols and practices of the EchoSense system to confirm that it did not create any new weakness or opportunity for intrusion.

Final details on the integration of EchoSense with project network and cybersecurity protocols are often described in a network access or cybersecurity agreement. This agreement can also outline responsibilites for detecting and reporting any unusual activity or potential threats, as well as support and cooperation with any actions taken by the wind farm O/O to address threats and thwart attacks.

As our understanding of the technology providers cybersecurity roles and responsibilities evolved it was apparent that our original approach to task 1 and the scope was not in line with how the issue was being addressed. Therefore, Natural Power and the Department of Energy ("DOE") agreed that development of this report was a better approach for documenting wind farm O/O NERC CIP compliance expectations and lessons learned as a technology provider.

2.1. What is NERC CIP and why does it matter?

The North American Electric Reliability Corporation ("NERC") is a not-for-profit international regulatory authority whose mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid (https://nerc.com/pages/default.aspx). NERC develops and enforces Reliability Standards; annually assesses seasonal and long-term reliability; monitors the bulk power system through system awareness; and educates, trains, and certifies industry personnel. NERC's major duties involve working with all participants to develop standards for power system operation, monitoring and imposing compliance with those standards, evaluating resource adequacy, and providing educational and training resources as part of an accreditation program to ensure power system operators remain competent and adept. NERC also investigates and analyzes the causes of significant power system disturbances to help prevent future events.

Critical Infrastructure Protection ("CIP") standards.

NERC CIP defines the reliability requirements for planning, operating, and protecting the North American bulk power supply system. NERC CIP covers all aspects of protection from physical protection to virtual private networks, username and password management, encryption, failed log-in attempts, reporting requirements, disaster recovery in case of a successful attack, etc.

NERC CIP compliance should start during the system planning stage and continue with its integration at the wind farm and remain until the system is removed from the site. Risks and threats will change over time so the technology development must be able to accommodate and respond to those changes. A recent example, December 2021, is the discovery of the Log4j vulnerability (see side box) within the Java library for logging error messages. Natural Power clients requested that the company assess the use of Log4j libraries in the EchoSense acoustic software and decision-making software as well as the cloud (Azure) infrastructure and services. This investigation required review by four experts over the course of one week to determine that no such vulnerability existed within the EchoSense system.

Log4j vulnerability in December 2021

Log4Shell is a software vulnerability in Apache Log4j 2, a popular Java library for logging error messages in applications. The vulnerability, published as CVE-2021-44228, enables a remote attacker to take control of a device on the internet if the device is running certain versions of Log4j 2.

The Log4j 2 library controls how applications log strings of code and information. The vulnerability enables an attacker to send a string to an application, which tricks the application into requesting and executing malicious code under the attacker's control. As a result, attackers can remotely take over any internet-connected service that uses certain versions of the Log4j library anywhere in the software stack.

The Apache Software Foundation, which publishes the Log4j 2 library, gave the vulnerability a CVSS score of 10 out of 10, the highest-level severity score, because of its potential for widespread exploitation and the ease with which malicious attackers can exploit it.

Source: Dynatrace 2021

The NERC CIP documentation covers more than 400 pages across 12 key topics and the guidance is periodically updated (https://www.nerc.com/pa/Stand/Pages/ReliabilityStandardsUnitedStates.aspx). Table 2.1 summarizes the purpose of each area as well as their relevance to Wind Wildlife technology developers.

Table 2.1: North American Electric Reliability Corporation Critical Infrastructure Protections Standards as they relate to third-party wildlife technology

Standard Version	Title	Technology Development Relevance	Purpose
CIP-002-5.1a	Cyber Security — Bulk Electrical System ("BES") Cyber System Categorization	The higher the category the more stringent the compliance required.	To identify and categorize BES Cyber Systems and their associated BES Cyber Assets for the application of cyber security requirements commensurate with the adverse impact that loss, compromise, or misuse of those BES Cyber Systems could have on the reliable operation of the BES. Identification and categorization of BES Cyber Systems support appropriate protection against compromises

Standard Version	Title	Technology Development Relevance	Purpose
			that could lead to misoperation or instability in the BES.
CIP-003-8	Cyber Security — Security Management Controls	How will you detect unauthorized access? How will this be communicated to the wind farm O/O? Are industry standard protocols being used? Who is the point of contact at the technology developer?	To specify consistent and sustainable security management controls that establish responsibility and accountability to protect BES Cyber Systems against compromise that could lead to misoperation or instability in the BES.
CIP-004-6	Cyber Security — Personnel & Training	Personnel requirements and training for staff working on the wildlife technology and/or the wind farm on site or remotely. What training will be provided regarding USB drives, laptops, file transfer protocols, handling of potentially sensitive information, remote access, user authentication and credentials, Encryption, disposal of hardware?	To minimize the risk against compromise that could lead to misoperation or instability in the BES from individuals accessing BES Cyber Systems by requiring an appropriate level of personnel risk assessment, training, and security awareness in support of protecting BES Cyber Systems.
CIP-005-6	Cyber Security — Electronic Security Perimeter(s)	Incudes the ingress and egress of data from the wind farm network. What data will be transmitted by the system? Will the communication be bidirectional or unidirectional? How will access be provided to the wind farm O/O network (e.g., firewalls)? What data transfer protocols are being use?	To manage electronic access to BES Cyber Systems by specifying a controlled Electronic Security Perimeter in support of protecting BES Cyber Systems against compromise that could lead to misoperation or instability in the BES.
CIP-006-6	Cyber Security — Physical Security of BES Cyber Systems	Addresses the physical access to the wildlife system. Typically, the wind farm O/O bears most this responsibility as they maintain the physical security at the wind farm.	To manage physical access to BES Cyber Systems by specifying a physical security plan in support of protecting BES Cyber Systems against compromise that could lead to misoperation or instability in the BES.
CIP-007-6	Cyber Security — System Security Management	Addresses how the system will be maintained in the long-term (e.g., security patches for servers, malicious code prevention). How will patches be applied? How quickly after release will it be applied? Will the developer test the patch with the system to confirm the patch does not alter system function? Will all events be logged (e.g., sign in attempts, etc.)	To manage system security by specifying select technical, operational, and procedural requirements in support of protecting BES Cyber Systems against compromise that could lead to misoperation or instability in the BES.

Standard Version	Title	Technology Development Relevance	Purpose
CIP-008-6	Cyber Security — Incident Reporting and Response Planning	The technology is responsible for monitoring for attacks, detecting attacks, and communicating these events to the wind farm O/O. Support the wind farm O/O in a response. How will the technology developer detect potential attacks/ How will these be reported to the wind farm O/O? What responsibilities will the technology developer have in responding to these incidents?	To mitigate the risk to the reliable operation of the BES as the result of a Cyber Security Incident by specifying incident response requirements.
CIP-009-6	Cyber Security — Recovery Plans for BES Cyber Systems	How will the technology operation be restored in the event of a successful attack? How long is this recovery expected to take? What is needed for the recovery (replace hardware, restore to the previous version of the software?)	To recover reliability functions performed by BES Cyber Systems by specifying recovery plan requirements in support of the continued stability, operability, and reliability of the BES.
CIP-010-3	Cyber Security — Configuration Change Management and Vulnerability Assessments	How will changes in technology configuration be tracked? Will a vulnerability assessment be completed before each configuration change?	To prevent and detect unauthorized changes to BES Cyber Systems by specifying configuration change management and vulnerability assessment requirements in support of protecting BES Cyber Systems from compromise that could lead to misoperation or instability in the BES.
CIP-011-2	Cyber Security — Information Protection	What were the security conditions during the development of the system/software? Is the source code stored securely? How is unauthorized access prevented?	To prevent unauthorized access to BES Cyber System Information by specifying information protection requirements in support of protecting BES Cyber Systems against compromise that could lead to misoperation or instability in the BES.
CIP-013-1	Cyber Security - Supply Chain Risk Management	What processes are used in the procurement of wildlife technology systems to identify and assess cyber security risk(s) to the BES from vendor products or services resulting from: (i) procuring and installing vendor equipment and software; and (ii) transitions from one vendor(s) to another vendor(s)	To mitigate cyber security risks to the reliable operation of the BES by implementing security controls for supply chain risk management of BES Cyber Systems.

Standard Version	Title	Technology Development Relevance	Purpose
CIP-014-2	Physical Security	Only relevant if the technology affects or resides at a transmission station or substation.	To identify and protect Transmission stations and Transmission substations, and their associated primary control centers, that if rendered inoperable or damaged as a result of a physical attack could result in instability, uncontrolled separation, or cascading within an interconnection.

Source: NERC CIP and Natural Power

2.2. Wind Wildlife Technology

The DOE has funded several rounds of technology development for deterrent and smart curtailment devices aimed at minimizing impacts to bats and birds at wind farms. There are more than a half-dozen different manufacturers of these devices. For these technologies to become long term commercial successes, they must be effectively integrated into the wind plant network systems (e.g., Supervisory Control and Data Acquisition “SCADA” controls) and workflows (e.g., malware patching) as well as meet the ongoing cybersecurity expectations of the operator. If the integration of the technology does not meet NERC CIP (or more stringent wind farm O/O) requirements, this may delay deployment on a large scale and prolong the risk of the species that need protections. Those in the detection and deterrent domain should understand and integrate NERC CIP and other common industrial cybersecurity standards (multi-factor authentications, private keys, etc.) rather than develop the technology in a vacuum (AWWI 2018).

Planning for NERC CIP standards begins when the technology development process starts and continues for the life of the product. This long-term adherence to the standard requires flexibility from the technology developer as the NERC CIP standards evolve over the long lifecycle (>20 years) of a wind farm, as threats changes, and as each client will interpret the NERC CIP standards from their unique perspective. We have seen examples of this, in which different clients perceive risks to certain approaches differently (e.g., use of cloud vs. on-site computing resources). So, despite calls for standardization, the continuing development of wind-wildlife technology along with legacy system integration, client preferences, and other variables will create challenges for technology providers and developers and likely require some level of customization for each system installation.

Devices that integrate with the on-site network (“comms”) or Supervisory Control and Data Acquisition (“SCADA”) or are otherwise behind the corporate firewall of the wind farm O/O will need to meet the cyber security expectations and requirements of the wind farm O/O. These will vary dramatically by wind farm O/O.

Some basic considerations:

- Depending on its design a system may require more or less cybersecurity. The device may reside exclusively external to the on-site or corporate network, or they may reside in the wind farms SCADA/plant controller. There are layers of security. Penetrating more layers means more in-depth coordination between the technology provider and the end-user. (AWWI 2018)
- These devices are likely to operate for years, maybe even the entire lifespan of the plant, including repowering.
- The cybersecurity threats are likely to change overtime (new sort of cyber-attacks).
- Devices may involve turbine curtailment, which require communication with the SCADA and/or in-turbine controls.
- To get the most reliable functionality at the plant or fleet level, there will need to be some level of integration between the external wildlife technology system and the wind power plant SCADA/control system. (AWWI 2018)
- During the lifetime of the plant there will be multiple revisions of the software applications for a subset of the systems of the plant. Reducing the effort related to restoring wildlife mitigation functionality after such upgrades is desirable. These upgrades may not be compatible (stop or interfere with) or may create unexpected operational actions by the wildlife technology.
- Due to security concerns, there will be increasing requirements and changing security protocols that protect the operation of the SCADA control system from unauthorized manipulation. (AWWI 2018)

3. Stakeholder Complexity

The Wind Wildlife technologies are new and potentially create new cybersecurity risks for adopters, as such the technology will face intense scrutiny from a wide range of stakeholders to ensure compliance. Stakeholders may include information technology staff and cybersecurity experts at the wind farm, fleet, and/or corporate level, as well as O&M personnel and subcontractors.

All stakeholders will not be involved in all aspects of the project from start to finish but there will typically be a few participants during the earliest discussions (at this point the purchaser is working to understand the system and its requirements). Next there is a substantial increase in participants (while the system is being reviewed and accepted by the relevant technical subject matter experts), and then decreases to just a few key technical individuals for the actual installation and integration. Finally, there is a further decrease to just one or two experts who continue to engage with the technology and technology developer for the reminder of the product life at the wind farm (patches, troubleshooting).

It is not possible to define all possible cybersecurity risks or concerns, be it at the turbine controller or at the detection and deterrent system level. The types of risk and areas of concern will vary between wind farms and owner-operators and Original Equipment Manufacturers. The responsibility for each risk needs to be well described and assigned in the contractual documents (e.g., Network Access Agreement).

From the wind farm operator's perspective, the Wind Wildlife technology must NOT create any new weaknesses or opportunities in the cybersecurity framework that protects both the wind farm and the larger corporate network (including regional or national control centers), it must NOT create an out-of-compliance issue for the wind farm O/O. Data and operational cybersecurity requirements embodied in the NERC and other security standard must be continuously addressed for the entire project lifecycle. If there are any breaches or risks, the wind farm operator needs tools to address these risks/breaches as fast and effectively as possible. This may require shared access to some or all system components (e.g., servers, other hardware with connection to the internet). Coordination of this access is essential because a patch applied to a server, without first testing it with the technology software, may result in a system malfunction (e.g., no operation or non-standard operation).

Table 3.1: **Sample requirement from the technology purchaser**

Topic	Requirements	Discussion
Wildlife protection system data security	It shall be possible to secure the wind farm from external disruption of operation	Unless the Wind Wildlife technology is independent of the wind farm control systems, data security regulations or policies need to be observed by the Wind Wildlife technology, so that these do not prose a weak link in the defense against cyberattacks on the wind farm.
Reporting	It shall be possible to collect data for reporting	Reports may include events, duration, timing, source of attempt. An actual report may not need to be generated but the data for tracking these events needs to be generated, collected, and warehoused to implement continuous improvements and demonstrate compliance with regulations.
Alarms	It shall be possible to detect and highlight issues that require attention (e.g., numerous failed log-on attempts)	This creates a systematic and strategic process to respond to alarms. Focus efforts on issues that need to be addressed immediately (breach) and those that can be dealt with later (persistent but unsuccessful attacks).

Topic	Requirements	Discussion
Remote support	It shall be possible to get remote support for troubleshooting	Remote control will have data security implications and any kind of impact on the data security shall be documented.

Source: Adapted from The American Wind Wildlife Institute (AWWI). 2018. AWWI White Paper: Integration of Wildlife Detection and Deterrent Systems in Wind Power Plants. Washington, DC. Available at www.awwi.org. © 2018 American Wind Wildlife Institute.

System side resilience

System designers need to consider breaches and what the response to each issue shall be. This is the approach of NERC CIP. These responsibilities may be shared between the technology developer and the wind farm O/O but most frequently the wind farm O/O takes the lead, and the technology developer provides any requested or required support.

Relevant issues to consider include the severity of the risk and outcome if a breach or noncompliance event occurs, costs of responding, and regulatory implications. Developers and operators should consider these scenarios and develop plans in advance, so that operators can respond appropriately should these issues occur. (AWWI 2018)

4. Best Practices

Through this process, Natural Power has distilled some best practices for Wind Wildlife technology developers.

5. Integrate NERC CIP early and throughout the development. Plan for Defense-in-depth.
    - Defense-in-Depth refers to a strategy the employs multiple security measures to protect a company's resources. The core functionality is to provide additional layers of security as a backup to ensure malicious threats are stopped along the way. (Homeland Security External report: Control Systems Cyber Security: Defense in Depth Strategies, 2006)
    - Considering NERC CIP (and client specific) requirements from the start of the development process is critical but balanced so it can adapt to the requirements of the specific site or wind farm O/O. By considering NERC CIP at the start of the development stage, the process of integrating these third-party technologies into effectively operating wind farms can be streamlined and the end user will have a better experience using the new technology as an integrated part of their plant management strategy.

6. Understand how you plan to integrate into the wind farm O/O system.
    - The deeper the device resides in the site/corporate network, the more cyber awareness and practices are needed.
    - There are layers of security. Penetrating more layers means more in-depth coordination between the technology provider and the end-user.
7. Plan for the future of the system.
    - These devices are likely to operate for years, maybe even the entire lifespan of the plant, including repowering. Over this time the cybersecurity threats are likely to change overtime (new sort of cyber-attacks).
    - During the lifetime of the plant there will be multiple revisions of the software applications for a subset of the systems of the plant. Reducing the effort related to restoring wildlife mitigation functionality after such upgrades is desirable. These upgrades may interfere with (or stop) the operation of the wildlife technology. The upgrades may also trigger unexpected or unwanted actions by the wildlife technology.
8. Understand the trade-offs between integration and independence.
    - To get the most reliable functionality at the wind farm or fleet level, there will need to be some level of integration between the external Wind Wildlife technology and the wind farm SCADA/control system.
9. Retain flexibility and capability to respond.
    - Due to security concerns, there will be increasing requirements and changing security protocols that protect the operation of the SCADA control system from unauthorized manipulation.

5. References

1. American Wind Wildlife Institute (AWWI). 2018. AWWI White Paper: Integration of Wildlife Detection and Deterrent Systems in Wind Power Plants. Washington, DC. Available at www.awwi.org. 2018 American Wind Wildlife Institute. Prepared By Kaj Skov Nielsen, Independent Consultant.
2. Dynatrace. 2021. What is Log4Shell? The Log4j vulnerability explained (and what to do about it).https://www.dynatrace.com/news/blog/what-is-log4shell/#:~:text=Log4Shell%20is%20a%20software%20vulnerability,certain%20versions%20of%20Log4j%202
3. North American Electric Reliability Corporation. https://nerc.com/pages/default.aspx Accessed February 24, 2022
4. NERC Board of Trustees. 2021. Reliability and Security Technical Committee Charter. Approved November 4, 2021. https://www.nerc.com/comm/RSTC/RelatedFiles/RSTC_Charter_Board_Approved_Nov_4_2021.pdf
5. History of NERC. August 2020. https://nerc.com/news/Documents/NERCHistoryBook.pdf
6. NERC. United States - Mandatory Standards Subject to Enforcement. https://www.nerc.com/pa/Stand/Pages/ReliabilityStandardsUnitedStates.aspx Accessed February 24, 2022.
7. Homeland Security External Report # INL/EXT-06-11478, Contol Systems Cyber Security: Defense in Depth Strategies, Prepared by Idaho National Laboratory, May 2006. Recommended Practice: Defense-in-Depth (energy.gov)

10.2 Appendix B – Task 2: Integration with a Commercial Utility-scale Turbine Final Report

U.S. DEPARTMENT OF ENERGY

SubTask 2.5 Deliverable

Award Number:	DE-EE0008900
Originating FOA:	DE-FOA-0001924: Advanced Wind R&D to Reduce Costs and Environmental Impacts
Recipient:	Natural Power Consultants, LLC
Principal Investigator:	Jared Quillen, Ecologist
Project Title:	Bat Smart Curtailment; Efficacy and Operational Testing
Project Objectives:	The proposed project has two main goals: 1) test the efficacy of Bat Smart Curtailment (BSC) at the test site and 2) address operational concerns that are barriers to BSC adoption by wind farm operators, specifically North American Electric Reliability Corporation (NERC) Critical Infrastructure Protections (CIP) readiness and Original Equipment Manufacturer (OEM) Supervisory Control and Data Acquisition (SCADA) compatibility and interfacing.
Report Content:	Report on BSC Integration with commercial utility-scale turbine at the NWTC as described in SOPO 2.5
Version	1270496 - B

Task schedule and the impact of the Pandemic

The test plan called for the field testing to be completed in approximately one month (March to early April 2020); however, the study encountered a series of hurdles caused by or exacerbated by the COVID-19 pandemic. The pandemic prevented National Renewable Energy Laboratory ("NREL") staff from being on-site at the Flatiron campus for many months, starting in March 2020 and continuing for the remainder of the year. This repeatedly delayed the testing and delayed detecting procedural errors (e.g., extended SCADA shutdown times), which necessitated repeating the testing process. Additionally, the Flatirons campus experienced a series of operational problems, including an extended shutdown and repair of the substation and maintenance of the General Electric test turbine, which further delayed the testing. The testing was finally completed in the Spring of 2021.

1. Background

Natural Power received funding from the US Department of Energy ("DOE") to advance its Bat Smart Curtailment system ("BSCS") system. Task 2, entitled "BSC Integration with a commercial utility-scale turbine at the NWTC," was part of that effort. The BSC system was integrated with the Supervisory Control and Data Acquisition ("SCADA") data collection system associated with the General Electric ("GE") turbine. Relevant loads and power data was collected over one month, with testing planning to start in the spring of 2020. Analysis of this data demonstrated the loads and power effects of the BSC system on an individual utility-scale turbine and was assessed/quantified from the perspective of annual energy production (AEP).

A final test plan describing the work scope was submitted to DOE on April 12, 2020. The test plan described the objectives, test procedure, and data collection criteria. In addition, the document provided details about the turbine, instrumentation, data acquisition, and BSC system.

2. Test Objective

This test campaign focused on curtailment response and turbine mechanical loads measurements to assess any changes to component loads and fatigue life due to curtailment shutdown commands. The data collection and analysis process followed guidance from the International Electrotechnical Commission's (IEC) standard, Wind turbines – Part 13: Measurement of mechanical loads, IEC 61400-13, Edition 1.0, 2015, hereafter referred to as the Standard.

3. EchoSense System Equipment and Installation

The Bat Smart Curtailment System consists of hardware in two locations (Figure 7). A bat detector (ultrasonic acoustic detector) with two microphones is placed in the wind turbine nacelle. This test was initially scheduled to take place in March to April 2020 when bat activity is near zero, so an ultrasonic noise generator was developed to simulate bat presence. The ultrasonic noise generator was placed adjacent to the microphones. The speaker was controlled via a Raspberry Pi (small low-cost computer) that allowed for changes to the simulated bat activity schedule. The bat detector and Raspberry Pi were connected to the hardware in the data shed through fiber optic cables, a media converter, and Ethernet cables.

The BSCS server was housed in the data shed. It receives information from the bat detector and a wind turbine nacelle anemometer. It is connected to a CR1000X datalogger, which communicates with the turbine controller and issues the curtailment command based on the simulated bat calls and the wind speed values.

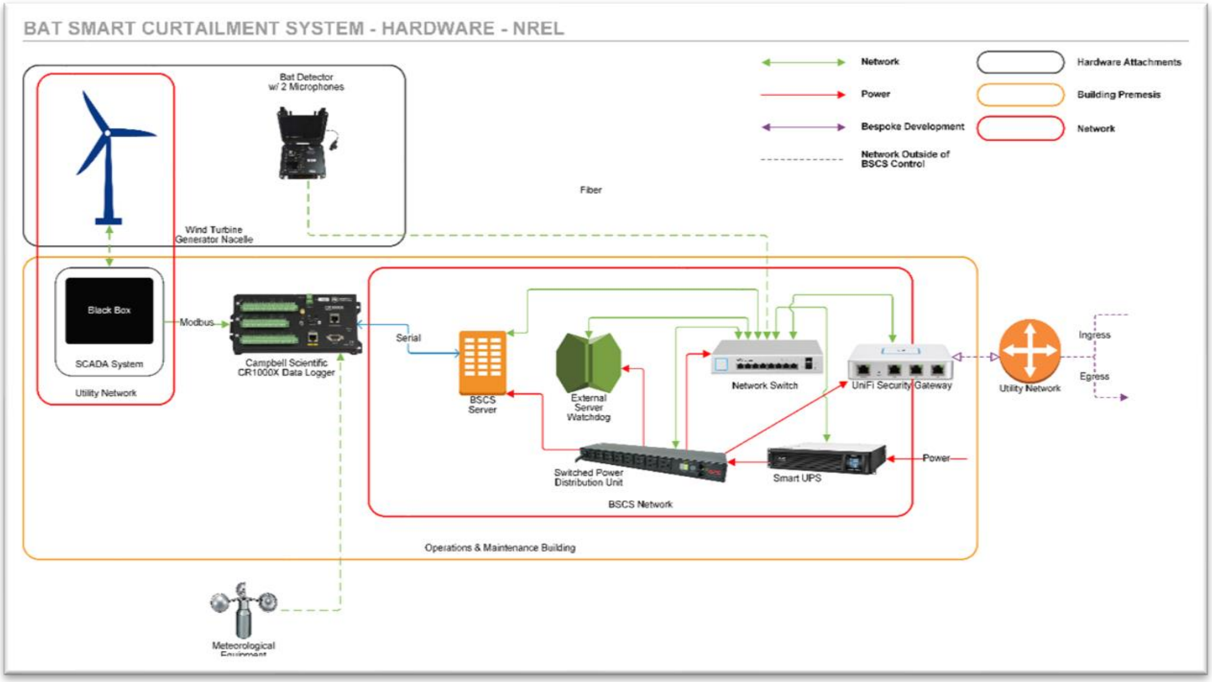


Figure 7. High-level overview of the BSCS

EchoSense Installation

In preparation for this campaign, the EchoSense system (formerly called Detection and Active Response Curtailment) was installed on the GE Wind Turbine Generator at the Flatirons Campus between March 2 and March 4, 2020 (Table 2). The system initially became operational on March 4. The campaign continued through the end of March 2021.

Table 2. EchoSense system equipment.

Acoustic Subsystem Installed in the wind turbine nacelle	Decision subsystem Installed In the data shed
Bat Acoustic detector with two microphones	BSCS server
Ultrasonic noise generator	Security gateway
Raspberry Pi	Network switch
Network switch	Power distribution unit
Cables and power supplies	Backup uninterruptible power supply

Acoustic Subsystem Installed in the wind turbine nacelle	Decision subsystem Installed In the data shed
	Raspberry Pi
	CR1000X data logger
	Cables and power supplies
	Backup Bat Acoustic detector with microphones

Source: Natural Power

The decision subsystem was installed in the local NREL lab (Figure 2). This subsystem manages the overall system, collects the data streams (e.g., bat activity, turbine condition, wind speed), and uses the data streams to apply rules regarding whether to curtail a turbine or not. This subsystem consists of a server and Campbell Scientific datalogger. The server is ingesting the data streams, and the datalogger is relaying the risk value and curtailment decision to the turbine SCADA system.

The acoustic subsystem was installed in the nacelle of the GE turbine (Figure 3). This portion of the system detects free-flying bats, but in Colorado, there are few to no free-flying bats present in March and April, so an ultrasound noise generated was used instead. It was programmed to generate 40kHz ultrasound pulses at intervals throughout the night.

Figure 9. The EchoSense decision subsystem in the NREL lab. The Campbell Scientific Datalogger and the Acoustic detector are connected to the server.

Figure 10. Natural Power and NREL staff up tower of the GE turbine while connecting the EchoSense system to the turbine network.

4. Test Turbine and Parameters

The test turbine is the DOE/GE 1.5 MW turbine owned by DOE and operated by NREL at the Flatirons campus (Figure 4). This machine is a unique research asset that has been fully instrumented for mechanical loads, electrical power, and turbine setpoints through previous DOE project investment. The major component loads measured and instrumentation that will be used are described in full detail in Santos and van Dam (2015).

The DOE/GE 1.5 SLE is a General Electric wind turbine rated at 1.5 megawatts with a 77-meter rotor diameter. This turbine generator system is pitch-controlled and equipped for parallel power grid operation. The three-blade rotor drives a planetary gear with spur wheel stages onto a double-fed induction generator with a frequency converter in the rotor circuit to enable variable-speed-operation. The test article consists of a three-section tubular tower with an internal ladder, nacelle, rotor blades, electric pitch drive, rotor hub and rotor shaft, gearbox, induction generator, hydraulic brake system, low voltage switchgear, and control system. Additional turbine details are listed in Table 3.

Figure 11. DOE/GE 1.5 SLE test article at Site 4.0 of the NWTC

Table 3. Test Turbine Configuration

Turbine manufacturer and address	GE Energy, 300 Garlington Rd., P.O. Box 648, Greenville, SC 29602-0648
Model	GE 1.5 SLE
Serial number	Nacelle head # W79227A
Rotor Diameter (m)	77
Hub Height (m)	80
Tower Type	Tubular
Rated Electrical Power (kW)	1500
Rated Wind Speed (m/s)	15 (for normal turbulence intensity)
Rotor speed range (rpm)	10 – 20
Fixed or variable pitch	Variable
Number of Blades	3
Blade Tip Pitch Angle (deg)	Variable
Blades make, type, serial number	GE37c, S00028, S00029, S00030
Description of control system (device & software version)	WindSCADA

Source: NREL

Turbine Load Components

Turbine component loads were measured at multiple locations noted in Table 4

Table 4. Load measurement details

Load	Unit	Description
Tower Base Bending	kNm	tower base bending moment from strain
Tower Top Bending	kNm	Tower top bending moment from strain
Tower Top Torque	kNm	Tower top torque from strain
Tower Top Acceleration NS	acceleration, g	tower top acceleration in the ~north-south orientation
Tower Top Acceleration EW	acceleration, g	tower top acceleration in the ~east-west orientation
Main Shaft Bending Moment	kNm	main shaft bending from strain
Main Shaft Torque	kNm	main shaft torque from strain
Blade 1 Flap Bending Moment	kNm	blade 1 flap bending moment from strain
Blade 1 Edge Bending Moment	kNm	blade 1 edge bending moment from strain
Blade 2 Flap Bending Moment	kNm	blade 2 flap bending moment from strain
Blade 2 Edge Bending Moment	kNm	blade 2 edge bending moment from strain
Blade 3 Flap Bending Moment	kNm	blade 3 flap bending moment from strain
Blade 3 Edge Bending Moment	kNm	blade 3 edge bending moment from strain

Source: NREL

Turbine Setpoint Measurements

Turbine setpoints are listed in .

Table 5. Turbine setpoint details

Turbine Setpoint	Unit	Description
Low-Speed Shaft RPM	RPM	Rotor speed
High-Speed Shaft RPM	RPM	Generator speed
Azimuth	Degrees	Rotor position
Blade 1 Pitch	Degrees	Blade 1 pitch angle
Blade 2 Pitch	Degrees	Blade 2 pitch angle
Blade 3 Pitch	Degrees	Blade 3 pitch angle
Yaw Encoder	Degrees	Nacelle yaw position
Turbine Status	-	Turbine SCADA status value

.

Table 5. Turbine setpoint details

Turbine Setpoint	Unit	Description
Low-Speed Shaft RPM	RPM	Rotor speed
High-Speed Shaft RPM	RPM	Generator speed
Azimuth	Degrees	Rotor position
Blade 1 Pitch	Degrees	Blade 1 pitch angle
Blade 2 Pitch	Degrees	Blade 2 pitch angle
Blade 3 Pitch	Degrees	Blade 3 pitch angle
Yaw Encoder	Degrees	Nacelle yaw position
Turbine Status	-	Turbine SCADA status value

Meteorological Signals

Meteorological signals and values are detailed in Table 6.

Table 6. Meteorological signal details.

Met Signal	Unit	Description
Temperature	°C	hub height air temperature from the met tower
Wind Direction	Degrees	hub height wind direction from met tower measured at 87m
Air Pressure	kPa	hub height air pressure from met tower
Wind Direction	Degrees	wind direction measured at 38m
Wind Speed	m/s	hub height wind speed from met tower measured at 80m
Nacelle Wind Speed	m/s	Wind speed from nacelle anemometer

Source: NREL

Data Acquisition System (DAS)

The DAS used for data collection was a National Instruments PXI real-time scan engine with distributed EtherCat chassis and C-series input modules. This system uses a deterministic EtherCat protocol that allows for exact synchronization of all signals. Every sample is GPS timestamped. The DAS hardware was paired with a PC running custom developed and validated LabVIEW code that was used to configure settings, control sampling rates, and write data files to a local hard drive.

Data was sampled at 1 kHz (the scan rate of the DAS) and then down-sampled to 50-Hz for storage and post processing. Data files contain a 10-minute time window. This process is repeated for consecutive time windows. In addition, standard deviation, minimum, and maximum statistics for each averaging period were determined in throughput processing and saved to the local hard drive.

5. Test Setup

Natural Power hardware was installed at the necessary locations. Installed equipment are listed in Table 2.

The turbine, meteorological tower, and DAS are maintained regularly and were prepared for the test as needed. New calibrations were determined for the blades, main shaft, and tower loads signals. These new calibrations are shown in Appendix A.

6. Test Procedure

The BSCS was programmed to generate bat activity from 18:00 to 06:00. This curtailed the turbine whenever the wind speed is in the region of interest (3.5 m/s - 12.5 m/s). Curtailment length was limited to 30 minutes, with at least 10 minutes of free operation between curtailment periods. This schedule was selected to maximize the number of curtailment events captured during the test.

While the original test procedure proved functional, the issued curtailment command to the turbine from the BSCS did not result in a shutdown of adequate rotor deceleration. For effective curtailment, the rotor needs to reach speeds below 2 RPM in less than 120 seconds. As a result, manual shutdown procedures were explored by NREL engineers to improve rotor deceleration times.

Four shutdown types were considered. Their characteristics are listed in Table 7.

Table 7. Curtailment type descriptions.

Type	Turbine Power Response	Turbine Pitch Response	Responsiveness
0-sec Park Shutdown	Power ramp down in ~12-15 seconds	Blades pitch out	<2RPM in ~ 100-110 seconds
30-sec Park Shutdown	Power ramp down in ~30-40 seconds	Blades pitch out	<2RPM in ~120 seconds
MHI Idle Command Shutdown	Power cut out immediately	Blades pitch out immediately	<2RPM in ~60-70 seconds
MHI Stop Command Shutdown	Power ramp down in ~30-40 seconds	Blades not pitched instead HSS Brake applied once the rotor speed falls below a threshold	Similar to 30-second Park shut down but **not** advised due to negative impact of braking

Source: NREL

From the shutdown response characteristics, it was determined that the Idle Command and the Zero-Second Park Shutdown were the most effective at reaching acceptable rotor deceleration rates to meet curtailment requirements.

The Idle Command was issued using the turbine’s machine human interface (“MHI”), located in the data shed. The Zero-Second Park Shutdown was commanded through the Wind Plant Controls toolbox, also located in the data shed. For this shutdown, the power ramp down rate was set to zero seconds. While in practice this is not what was achieved, likely due to overriding safety control logic, selecting the shortest ramp rate resulted in better rotor deceleration.

To implement these shutdown types all commands are user made as the process could not be automated. The following process was used for all curtailments (Figure 5):

1. Turbine allowed to reach load operation (power production)
2. Command issued, and timestamp noted
3. Wait period of 10-minutes (curtailment)
4. Curtailment released; startup command issued
5. Steps 1 through 4 repeated

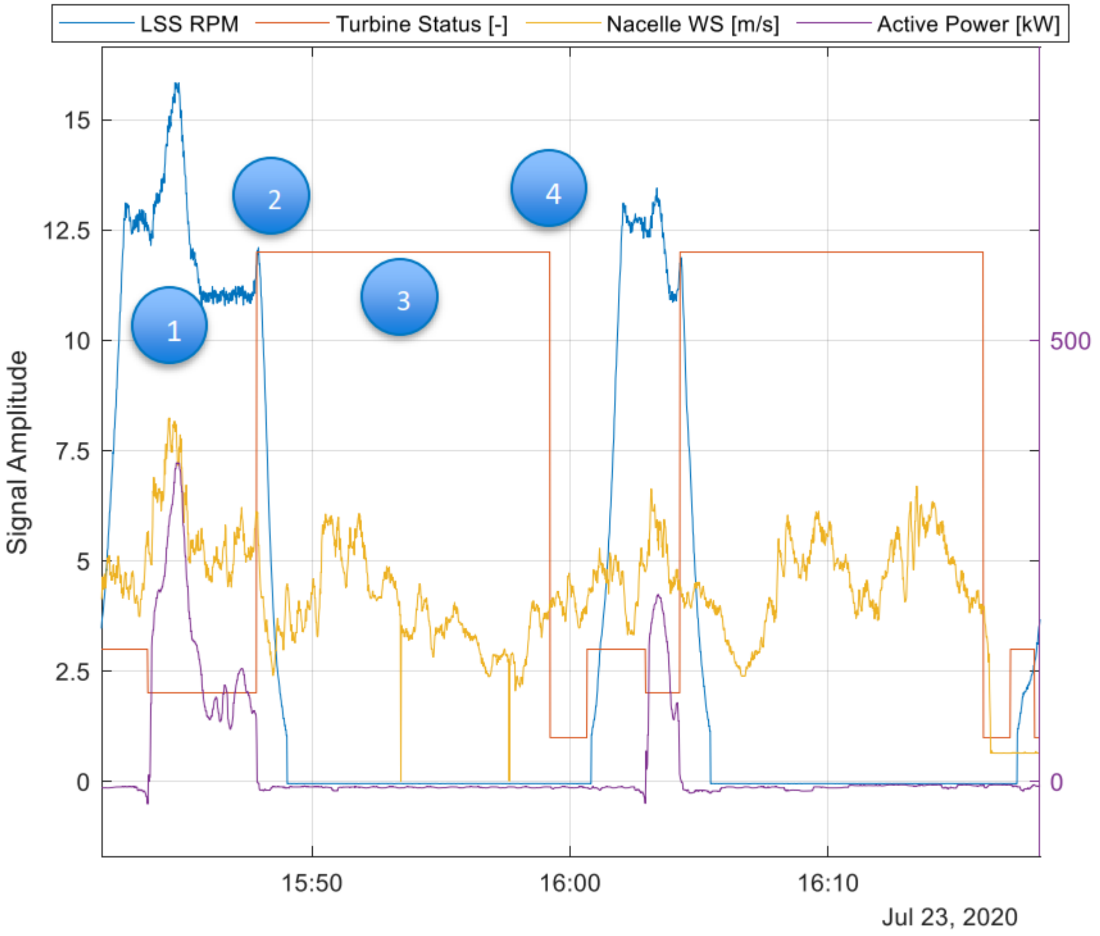


Figure 12. Illustrates the user commanded curtailment process, and each step is noted. The figure provides an example of rotor speed (LSS RPM), turbine status (a value of 12 indicates curtailment), inflow wind speed (Nacelle WS), and turbine power (Active Power, right y-axis scale).

7. Analysis Methods

All curtailment data files (50-Hz time-series) were processed to calculate engineering units of all loads signals using the calibration factors found in Appendix A.

The tower bending signals were calculated into the nacelle reference coordinate system and the fore-aft and side-to-side moments using yaw position. See Appendix B for the coordinate systems.

The method of bins was used, as per the Standard, to determine bin averages and bin standard deviations for operating loads and short-term damage equivalent loads (“DEL”). All data were binned using wind speed using 1-m/s bin widths centered on integers starting at 3-m/s and ending at 12-m/s.

The DELs for the operating moments were calculated in accordance with the Standard using appropriate Wöhler exponents without Goodman correction. The material slope (“m”) was 4 for the tower and main shaft loads, while a value of 10 was used for the blades. An exponent of 4 is typical for steel towers, whereas an exponent of 10 is more common for fiberglass and other similar composites used in blades. The material slopes are listed for each load group in Table 8.

Table 8. Material slopes used for fatigue analysis by load group

Load Group	Material Slope (m)
Blade root	10
Main shaft	4
Tower base	4

Source: NREL

The DEL calculations were carried out using MLife, a MATLAB-based postprocessing tool developed by NREL to analyze wind turbine test data, and aeroelastic/dynamics simulations. MLife uses the one-pass cycle-counting method of Downing and Socie for fatigue cycle counting. For the analysis in this report, a cycle count of 0.5 was assigned to unclosed cycles. A DEL provides an estimation of fatigue due to many, variable load cycles referenced to a 10- minute mean wind speed.

An example of the data processing steps and presentation in this report are shown in Figure 6, where the DEL scatter (red dots) are the individual DELs determined for each 10-minute time-series data file referenced against the 10-minute mean wind speed. The Binned values (blue markers and trend line) present the mean DEL for each wind speed bin referenced to the mean winds speed of each wind speed bin. The vertical lines at each Binned marker represent the DEL scatter within each bin as ±1 standard deviation (±1σ).

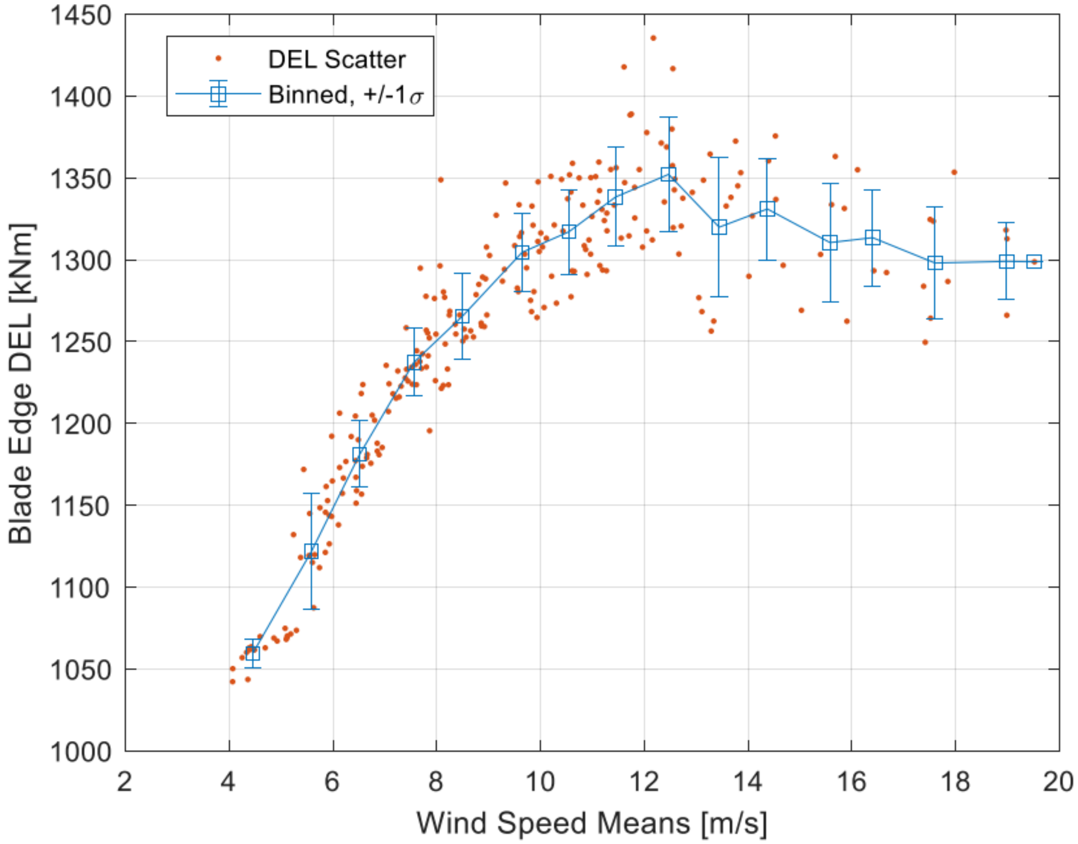


Figure 13. Example of wind speed binning of DEL scatter

While the targeted capture matrix included a minimum of three curtailments per wind speed bin in practice this was difficult to achieve due to the user commanded requirement to initiate a shutdown, the intermittent wind resources available during the summer months when data collection began, and other projects scheduled for run-time with the turbine. As a result, some wind speed bins fall short, but over the wind speed range that is most applicable to the BSCS sufficient data was captured (Table 9). Figure 7 provides a bar chart of the wind speed bins and number of curtailments captured within each bin for the two shutdown methods analyzed.

Table 9. Targeted Curtailment/Shutdown Capture Matrix

Wind Speed Bin Center [m/s]	4	5	6	7	8	9	10	11	12
Minimum # of shutdowns	3	3	3	3	3	3	3	3	3

Source: NREL

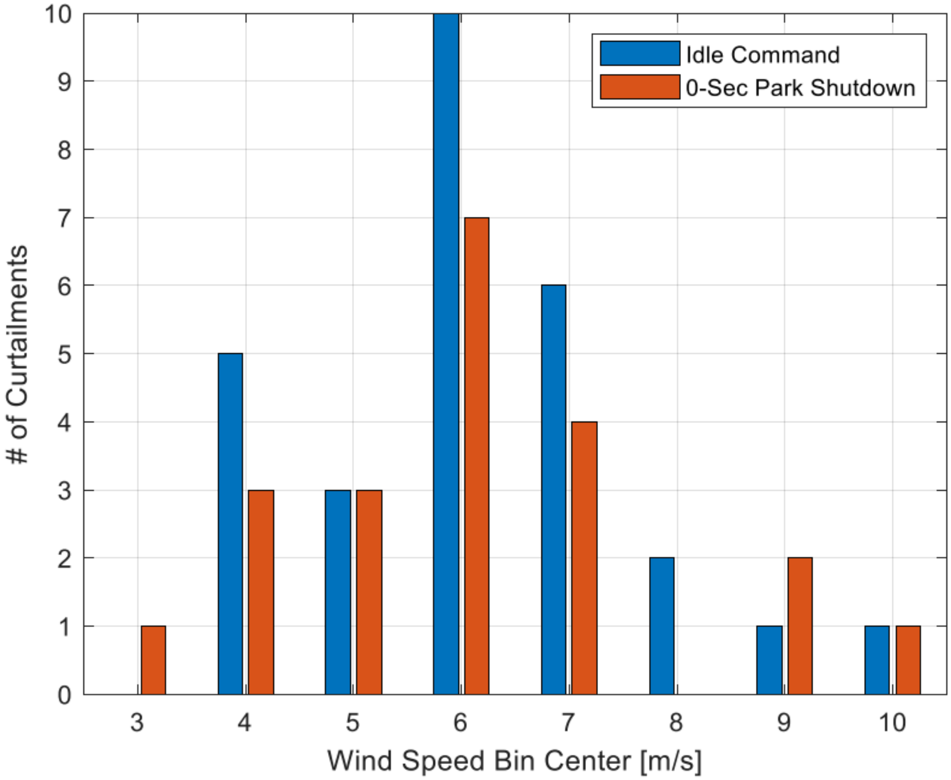


Figure 14. Bin count summary for each curtailment event

8. Results

The short-term DELs are plotted for Idle Command and Zero-Second Park Shutdown (0-sec Park Shutdown) with normal operation DELs (Normal Op). The normal operation DELs come from historical loads data collected on the turbine. In this way a comparison can be made regarding the curtailment impact to component fatigue versus normal uninterrupted operation.

Figure 8 and Figure 9 provide the results for blade flap and edge, respectively. While the Flap DELs for the curtailment data sets are larger than for normal operation, the Edge DELs have the opposite trend. In general, the Idle Command DELs are more favorable versus the 0-sec Park Shutdown. More importantly the magnitude of the DELs for the curtailment command data are very similar in magnitude and compared to the largest DELs from normal operation (edge DELs at rated wind speeds) the curtailment DELs are much smaller.

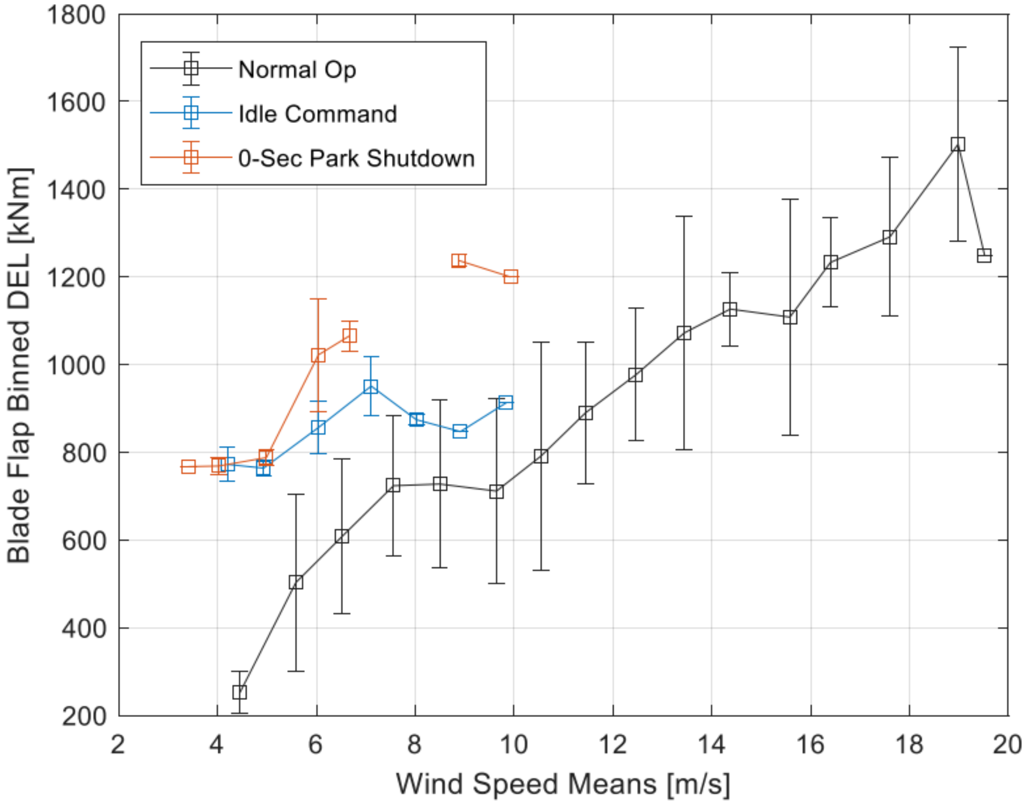


Figure 15. Blade flap short term fatigue results

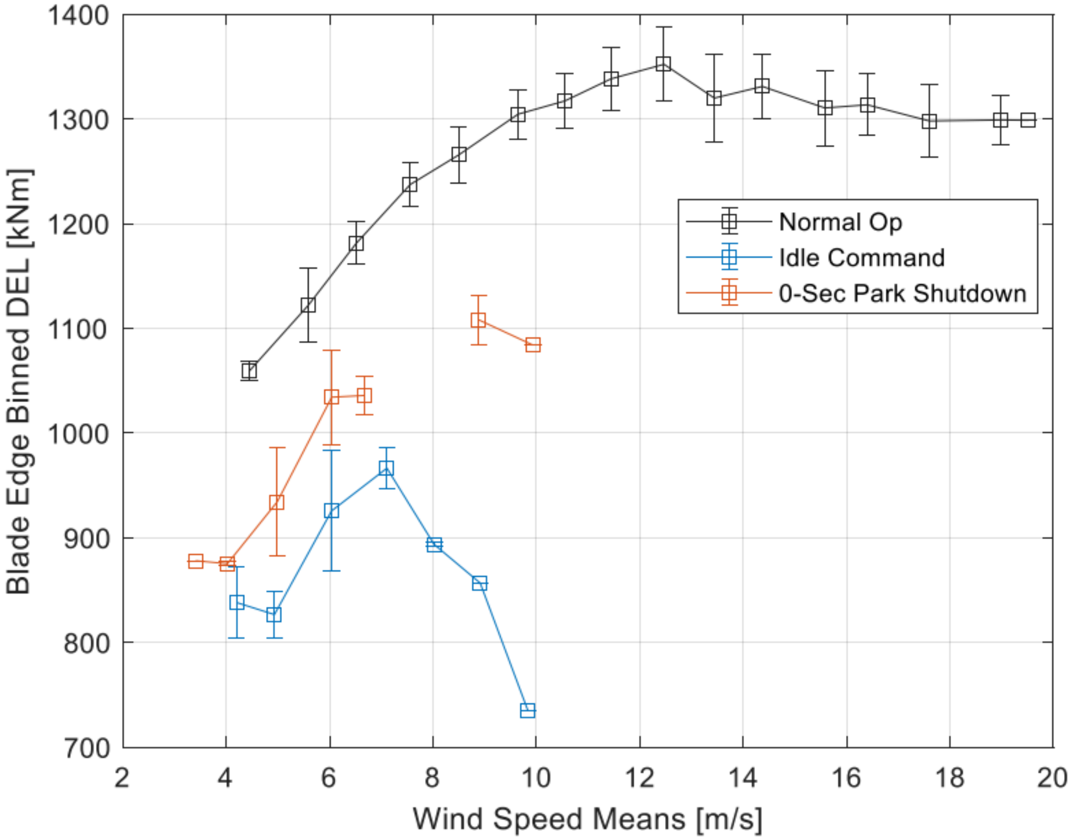


Figure 16. Blade Edge short-term fatigue results

To better understand the blade fatigue trend from the curtailment commands it helps to examine an example of time-series data during a curtailment. This is provided in Figure 10, where the top plot shows the rotor speed and nacelle wind speed, the middle subplot provides blade pitch, and the bottom plot shows the blade signals.

Two sections of the plot are highlighted with color boxes. The first box, in blue, highlights the period before curtailment begins when the turbine is operating normally. During this time, the flap signal has many small cycles with a large mean load and the edge has large cycles at the rate of rotation due to cyclic gravity loading as the rotor spins. In the second box, in red, the shutdown begins and the blades pitch to slow the rotor. As the blades pitch, the edge loads begin to transfer into the flap signal, as seen by the larger amplitude gravity load cycles in the flap response. From this it is expected that the flap and edge DELs will have similar trends for the curtailment data sets, where the large amplitude load cycles dominate the fatigue response. For the blade's circular root section this does not increase fatigue loads beyond cyclic gravity loading.

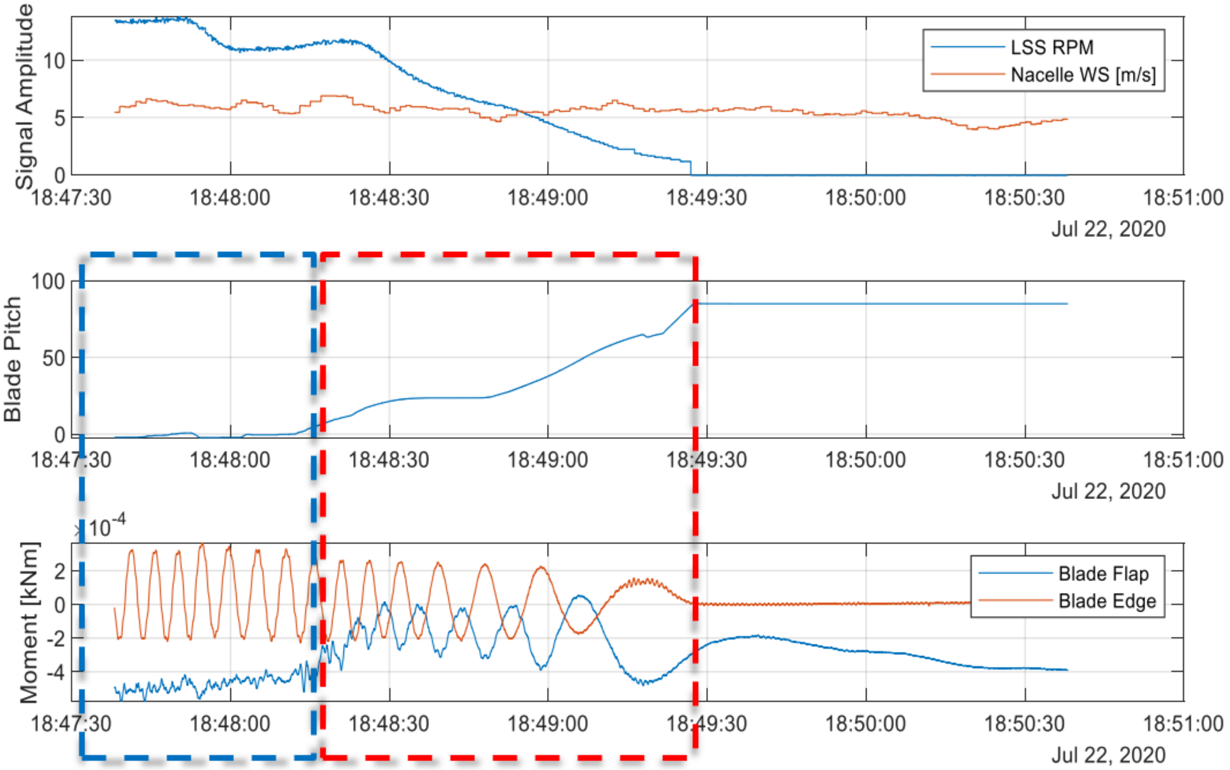


Figure 17. Example time-series data illustrating blade load trends during a curtailment event

The main shaft torque short-term DELs are plotted in Figure 11. Here the DELs are on trend with normal operation and within the bin scatter ranges. This implies shaft torque remains largely unaffected by the curtailment operations.

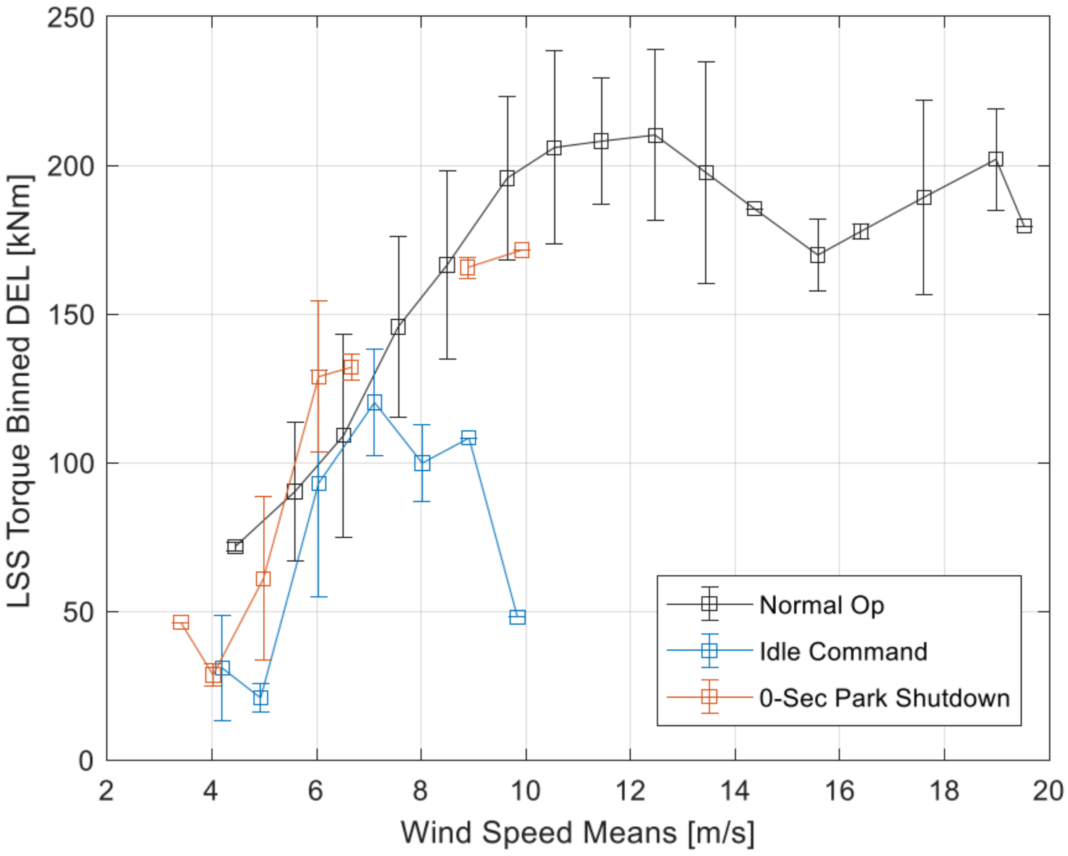


Figure 18. Main Shaft short-term fatigue results

The tower base load components are presented in Figure 12 and Figure 13 for the fore-aft and side-to-side DELs, respectively. The tower base DELs are below or at ranges consistent with normal operation. The Idle Command is more favorable in the fore-aft load component, but in the Side-to-Side the response is the same for both shutdown types and below normal operation.

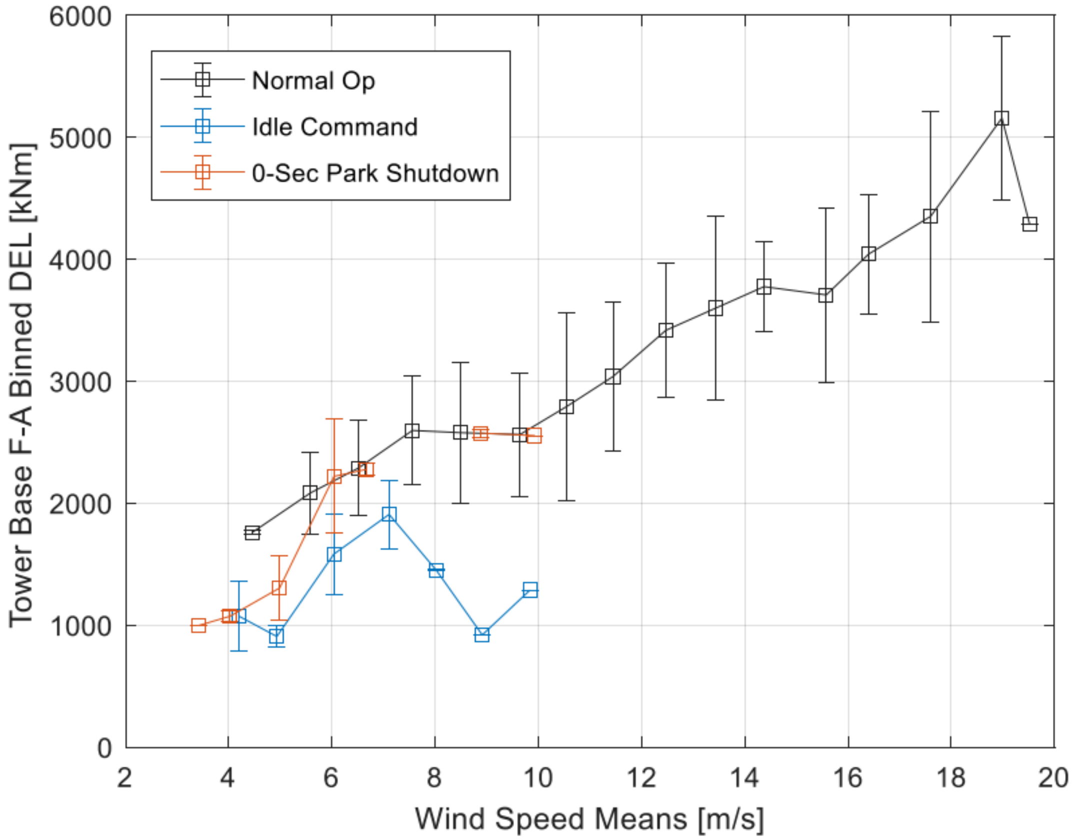


Figure 19. Tower Base Fore-Aft short-term fatigue results

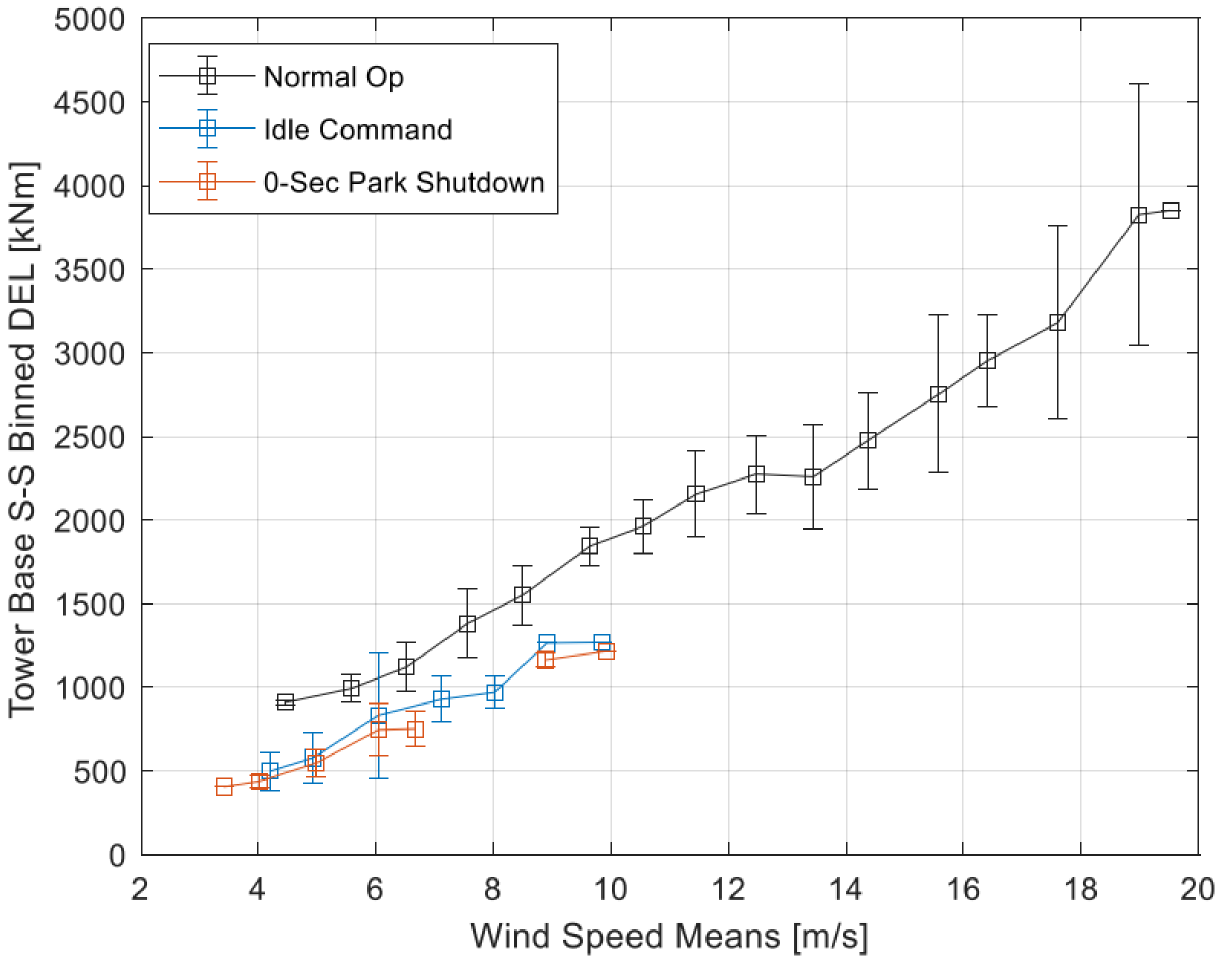


Figure 20. Tower Base Side-to-Side short-term fatigue result

9. Conclusions

The Natural Power BSCS was demonstrated on the NREL DOE/GE1.5 MW SLE wind turbine to determine loads impacts of a bat curtailment protocol. It was shown, however, that the curtailment command provided to the turbine did not result in acceptable rotor deceleration while the BSCS was installed for a realistic representation of turbine curtailment.

NREL engineers investigated shutdown options to meet the BSCS requirements and determined two methods: 1.) Idle Command from the turbine MHI and 2.) Park Shutdown with a zero second power down ramp rate commanded from the Wind Plant controller. These two methods required user commanded prompts (not automated) when wind speed and turbine conditions were acceptable.

Over several months (July 22nd, 2020, to February 2nd, 2021) a database of turbine response due to curtailment (shutdown) commands was collected and subsequently processed for scaled engineering loads and further processed for fatigue by the method of rainflow cycle counting to determine short-term damage equivalent loads (DELs).

The DEL results were compared with historical normal operation fatigue response (normal operation DELs) to determine the implications of curtailment on the fatigue life of the turbine under test.

From the curtailment process and fatigue analysis it was determined that blade flap fatigue loads increase compared to the respective normal operation wind speed bin, but the edge fatigue is reduced, and for the cylindrical cross section of the blade root no increase in fatigue is experienced; fatigue results are below normal operation range. It was shown that flap fatigue loads increase due to idling gravity loads from pitching during shutdown. Meaning the cyclic gravity loading is shared between flap and edge directions as the blades change pitch angle to decelerate the rotor.

The main shaft was shown to have general reductions in fatigue loads when compared to normal operation. Similarly, the tower base displayed a reduction in fatigue loads on parity with normal operation DELs.

Across load components, the Idle Command appears to have the most favorable response in terms of short-term fatigue and would be a preferable method for curtailment command for the turbine used in this demonstration.

Overall, the fatigue loads associated with curtailment due to the BSC system do not have an adverse impact to the turbine when assessed using short-term DELs for the GE1.5 SLE turbine used in this study. A lifetime fatigue analysis is suggested to fully understand the turbine design life implications.

10. Study Result Implications for EchoSense

Despite a successful demonstration of bat smart curtailment in 2015, the industry has been slow to adopt this tool due to actual and perceived risks. Therefore, the goal of this project is to test and validate the efficacy of a bat smart curtailment system in reducing fatalities and increasing energy production (Task 3) and address these other concerns. Task 1 addressed cybersecurity compliance. Task 2, which is the focus of this report, addresses a perception that turbines will experience excessive loads due to implementing bat smart curtailment. If they occur due to smart curtailment, excessive loads might impact operational costs and affect OEM warranties, which could be costly and discourage the adoption of EchoSense. Whereas addressing these issues and determining whether there are substantive concerns should remove barriers to adoption and make EchoSense a commercial success.

The results of this NREL-led loads study at the Flatirons campus suggests that undue mechanical stresses are absent when implementing the EchoSense system. The loads are within normal ranges and are not expected to increase stresses, reduce the life span, or otherwise be detrimental to the turbine’s mechanical systems. This work addresses a potential barrier to the broader adoption of the EchoSense curtailment system. A lifetime fatigue analysis is suggested to fully understand the turbine design life implications.

11. References

Freebury, G., and W. Musial 2000. Determining Equivalent Damage Loading for Full-scale wind turbine blade fatigue tests. Presented at the 19th American Society of Mechanical Engineers (ASME) Wind Energy Symposium

International Electrotechnical Commission's (IEC) standard, Wind turbines – Part 13: Measurement of mechanical loads, IEC 61400-13, Edition 1.0, 2015

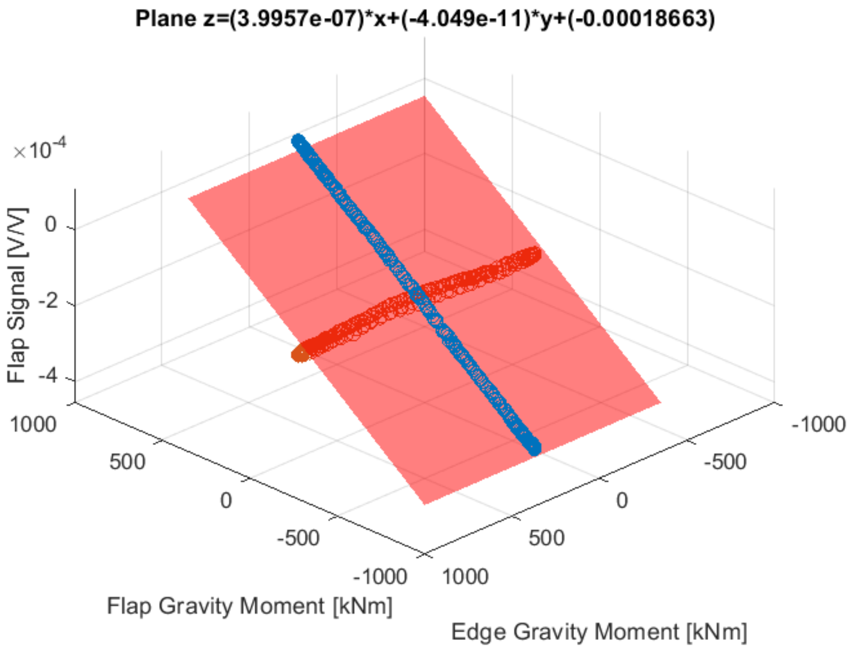
Santos, R. and J. van Dam, *Mechanical Loads Test Report for the U.S. Department of Energy 1.5-Megawatt Wind Turbine*, July 2015, NREL/TP-5000-63679. https://www.nrel.gov/docs/fy15osti/63679.pdf

DE-EE0008900.0000, Statement of Project Objectives (SOPO): Natural Power Bat Smart Curtailment: Efficacy and Operational Testing, 2020.

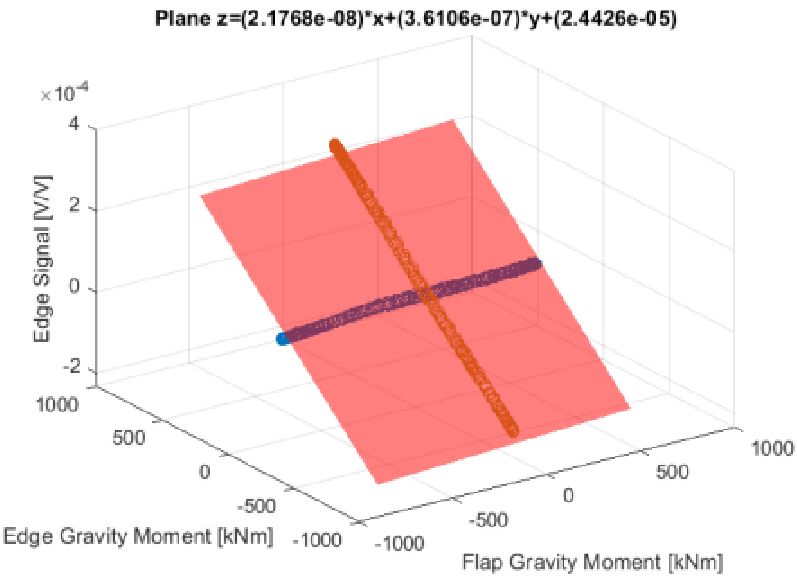
Appendix A. Loads Calibrations

Table 8. Blade calibration factors summary table

Blade Calibration Factors		
Flap [kNm/V/V]	3.9956854e-07	-4.0490329e-11
Edge [kNm/V/V]	2.1768297e-08	3.6106030e-07
	Flap [kNm/V/V]	Edge [kNm/V/V]
Offsets [V/V]	-1.866296e-04	2.442637e-05



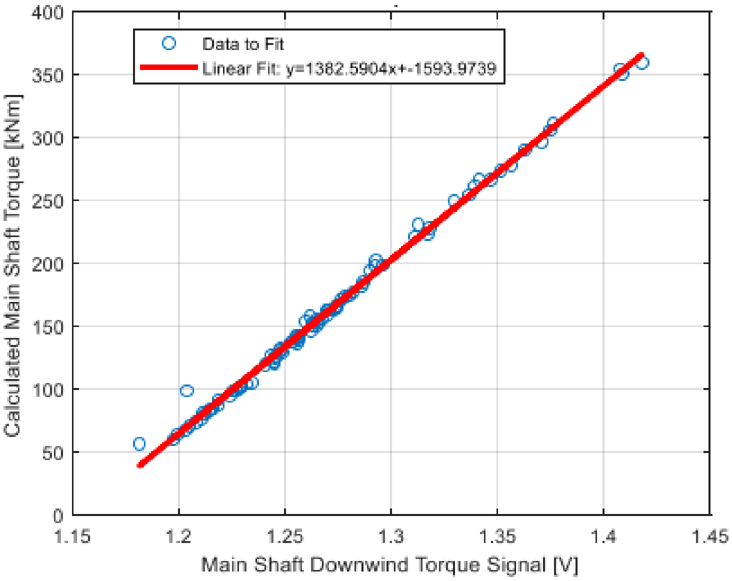
A 1. Blade flap calibration by plane fit method from rotor slow rolls



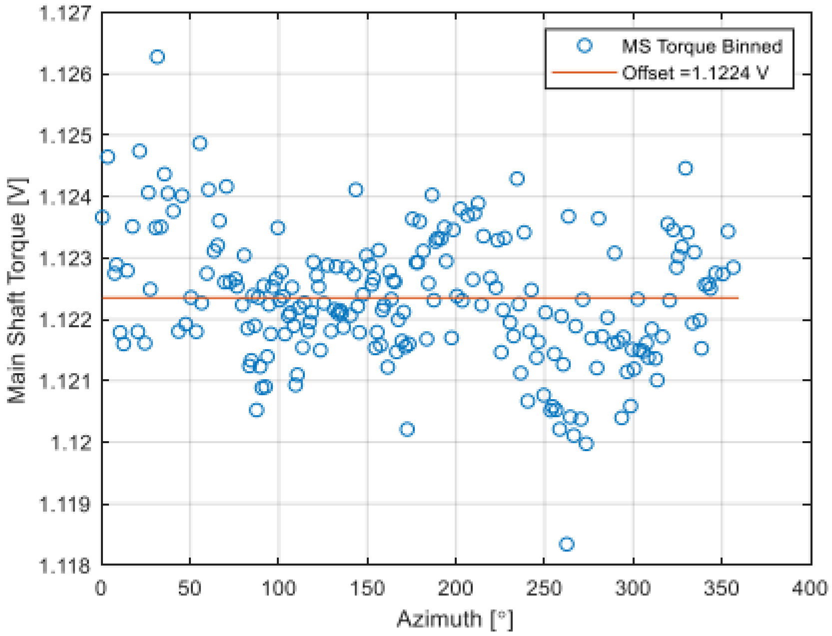
A 2. Blade edge calibration by plane fit method from rotor slow rolls

Table 9. Main shaft torque calibration factors summary table

Main Shaft Torque Factors		
Slope	1382	kNm/V
Offset	1.1224	V



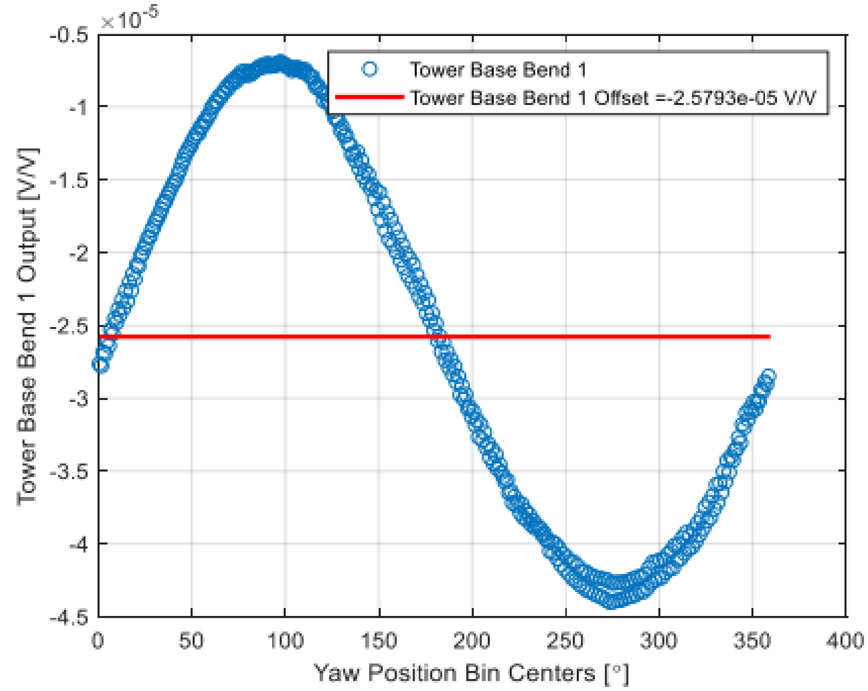
A 3. Main shaft torque linear fit to determine calibration slope



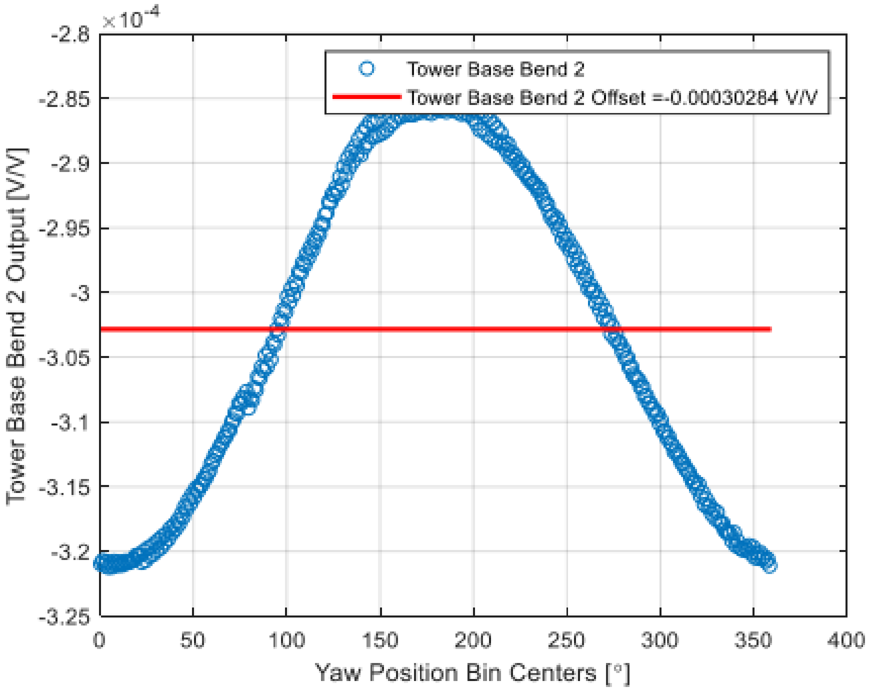
A 4. Main shaft torque offset calibration from rotor slow roll

Table 10. Tower base calibration factors summary table

Tower Base Factors				
Signal	**Sensitivities**		**Offsets**	
Bending 1	5.0892E+07	kNm/V/V	-2.5793E-05	V/V
Bending 2	5.1258E+07	kNm/V/V	-3.0284E-04	V/V

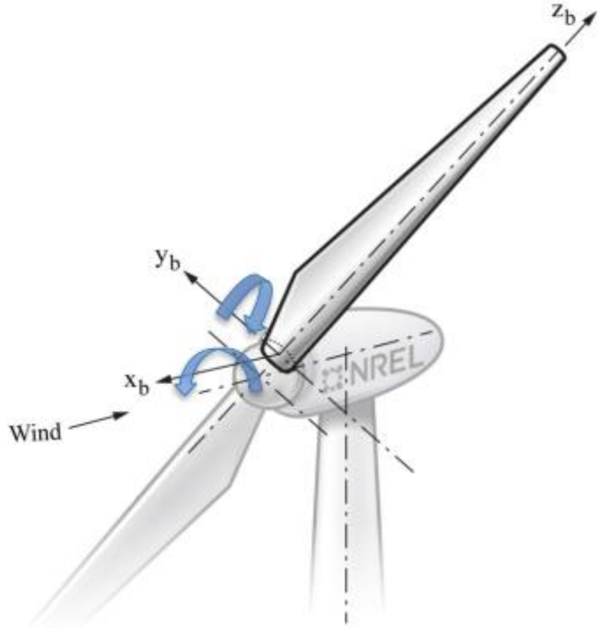


A 5. Tower Base bending 1 offset calibration

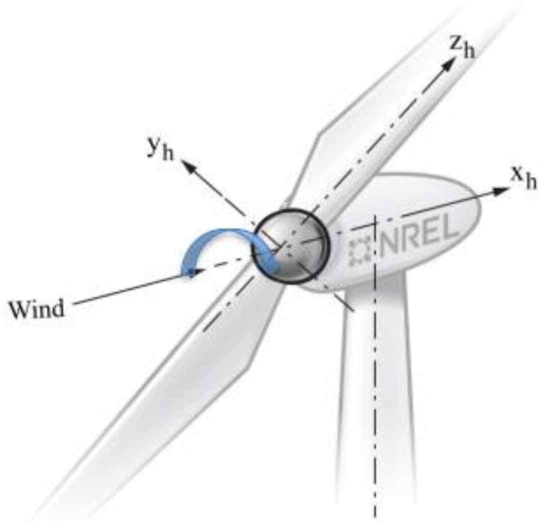


A 6. Tower Base bending 2 offset calibration

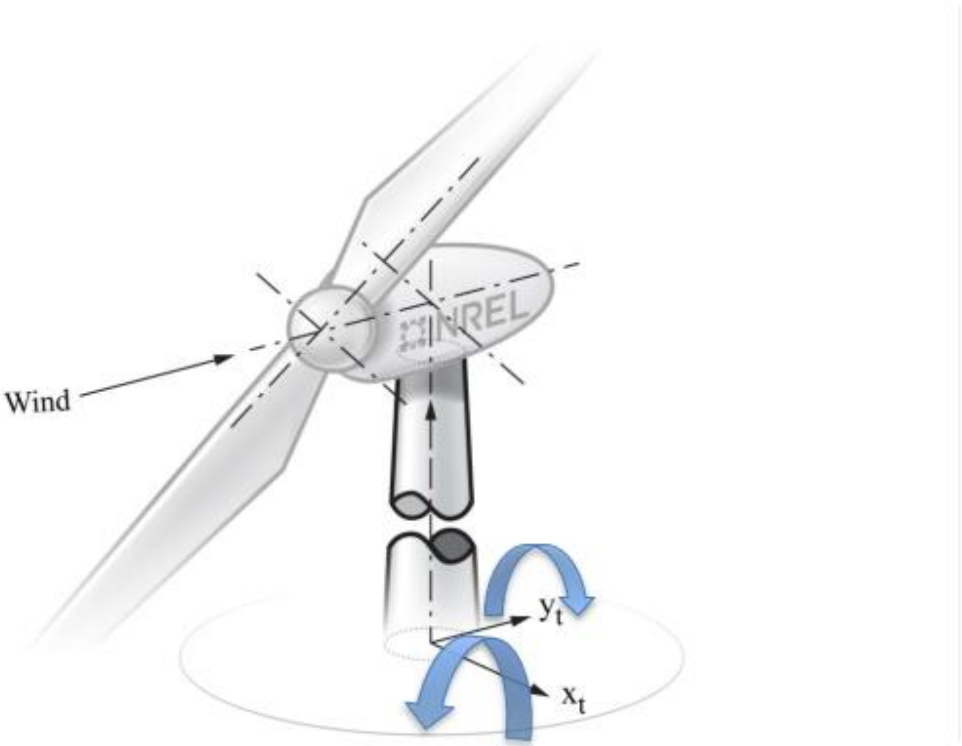
Appendix B. Coordinate Systems



A 7. Coordinate system for blade root flap and blade root edge bending moments



A 8. Coordinate system for main shaft torque



A 9. Coordinate system for tower base fore-aft and side-side bending moments

10.3 Appendix C – Task 3: Efficacy of a Bat Smart Curtailment System Final Report

DOE Task 3 Report - Year 1 & 2 FINAL

UNLIMITED VERSION
DOE Award (DE-EE0008900)

5 May 2023

US Department of Energy

Document history

Author	Gillian Vallejo, Senior Ecological Modeler Devin Saywers, Senior Project Engineer Roger Rodriguez, Principal Consultant	5/3/2023
Checked	Jared Quillen, Ecologist	6/28/2023
Approved	Kevin Denman, Head of Environmental Technology	6/28/2023

Client Details	
Contact	Joy Page
Client Name	US Department of Energy
Address	Golden Field Office

Issue	Date	Revision Details
Issue A	6/28/2023	Final version

Local Office:

Saratoga Springs, NY 12866
USA

Registered Office:

Natural Power Consultants LLC
Saratoga Springs, NY 12866
USA

Contents

Federal agency to which the report is submitted: Department of Energy, Office of Energy Efficiency & Renewable Energy, Wind Energy Technologies Office (WETO)

Recipient: Natural Power DUNS 0192561260000

Award Number: DE-EE0008900

Project Title: Bat Smart Curtailment: Efficacy and Operational Testing

Project Period: Budget Period 1

Principal Investigator: Jared Quillen, Ecologist, jaredq@naturalpower.com

Report Submitted by: Jared Quillen, Ecologist, jaredq@naturalpower.com

Date of report: June 28, 2023

Working Partners:

Alliant Energy - | Cedar Rapids, IA

Rizea Engineering – Steven Rizea, President

Cost Sharing Partners:

Alliant Energy - Cedar Rapids, IA

Renewable Energy Wildlife Research Fund

DOE Project Team

DOE HQ Project Officer – Nicholas Massey

DOE HQ Technical Project Officer – Raphael Tisch

DOE HQ Environmental Research Manager – Joy Page

DOE Field Contract Officer – Laura Merrick

DOE Field Grants Management Specialist – Stephanie Sites

DOE Field Project Monitor – Amy Sedlak

Signature of Submitting Official:

Acknowledgement: This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Wind energy Technologies Office (WETO), Award Number DE-EE0008900.

1. Abstract

Rapid growth in renewable energy generation is fundamental to reducing our reliance on fossil fuels thereby reducing our greenhouse gas emissions. Large-scale wind energy technology is playing a significant role in driving the switch to renewable energy, but it is not without environmental costs. The collision risk posed by the rotating blades of wind turbines to bats is one area that has been of increasing concern in recent years and has been predicted to result in hundreds of thousands of bat fatalities per year in North America alone. One way to minimize these collisions is to prevent turbines from operating when bats are likely to be present. This has typically been done by curtailing turbines at known periods of high bat activity based on time of year and wind speed. During periods when bats are most active, a threshold wind speed is established below which bat activity is likely to be highest and turbines are not allowed to operate. However, this type of operational curtailment can translate to a considerable loss of revenue. More recently, smart systems are being developed in which additional data are used to help determine the level of bat activity near the rotor swept zone of wind turbines. One such system is the EchoSense system, which combines wind speed data with bat activity data measured by acoustic detectors in real-time on site. These measurements are used to decide whether to curtail the turbines. Here, we present the results of a two-year case-study comparing the EchoSense system with a blanket curtailment approach in terms of both the financial benefits and the fatality rates associated with each. In the first year, a control treatment was also included in which no additional curtailment was used. We did not find a statistically significant difference in carcasses detected among any of the treatment groups in either year. In the first year this was likely due to a lack of statistical power, since turbine operational issues resulted in reduced sample sizes. In the second year, comparable numbers of carcasses were detected for both EchoSense, and blanket curtailed turbines and no significant effect was found among treatments, suggesting that the EchoSense system performs similarly to blanket curtailment in terms of bat fatalities at the study site. There was a significant reduction in energy loss associated with EchoSense curtailment compared to blanket curtailment of 41% in the first year and 56% in the second year. Use of the EchoSense curtailment system in place of blanket curtailment at this site would therefore be expected to translate into a considerable increase in annual revenue, similar in magnitude to the addition of another turbine to the site, while simultaneously keeping bat fatalities at a comparable rate to blanket curtailment.

2. Introduction

Renewable energy is a rapidly expanding industry due to the need to meet increasing energy demands while simultaneously mitigating the effects of global climate change. In the US, more than 20% of energy production was derived from renewable energy sources in 2021 (preliminary figures available at www.eia.gov, accessed 3/14/2022). Wind energy represents a substantial contribution to this figure, constituting 46% of renewable energy production. However, while renewable energy helps to reduce reliance on fossil fuels thereby reducing atmospheric carbon pollution, renewable energy itself can have negative environmental impacts. One such impact is the collision of flying animals, such as bats, with the rotating blades of wind turbines. Rates of bat collisions detected at wind farms in North America suggest that hundreds of thousands of bats per year are killed due to collisions with wind turbines (Arnett and Baerwald 2013; Zimmerling and Francis, 2016; Smallwood, 2020) and concern over the level of impact this could be having on bat populations to the point of potential extinction (e.g., Frick et al 2017;

Friedenberg and Frick 2021) has resulted in studies of minimization measures at wind farms. Such measures have especially been implemented to minimize the fatalities of federally listed species (USFWS 2020) and more recently for species that are most commonly found among fatalities (ACWRTAC 2022).

Bat fatality rates at turbines have been found to correlate negatively with wind speed (Kerns et al. 2005; Arnett et al. 2008; Schuster et al. 2015) suggesting that collision risk may be reduced at higher wind speeds when fewer bats are active. As a result of this understanding, a common minimization practice for bat fatalities at wind farms is to curtail turbines when the wind speed drops below a certain level, which might be determined on a site- or species-specific basis (Arnett et al. 2011; Baerwald et al. 2009). This practice of blanket curtailment has been shown to be effective in reducing bat fatalities (Baerwald et al., 2009; Arnett et al., 2011; Adams et al., 2021), but may also result in considerable losses in energy yield. For example, Arnett et al. (2011) estimated that raising the cut-in speed to 6.5 m/s for a period between July 27th and October 9th resulted in a 11% reduction in energy production during that time at their study site in Pennsylvania.

Bat acoustic activity near the rotor swept zone has also been found to correlate strongly with bat fatality rates (Roemer et al. 2017; Smallwood and Bell, 2020; Peterson et al. 2021). In recent years, several methods have been devised to use additional information to determine appropriate turbine curtailment thresholds to minimize bat fatalities including data relating to real-time bat exposure in the rotor swept area (Korner-Nievergelt et al., 2013; Behr et al., 2017; Hayes et al., 2019). Where bat activity is monitored, typically by acoustic methods, turbines may continue to operate in weather conditions suitable for bats, unless a threshold level of bat activity is also observed on-site. This involves processing real-time data, not only on weather conditions, as would be required during blanket curtailment methods, but also on real-time data relating to bat activity.

One such system is the EchoSense bat smart curtailment system developed by Natural Power. The EchoSense system utilizes an array of ultrasonic microphones to detect bat echolocation calls in the proximity of the rotor swept area as an indicator of bat exposure and aligns those data with real-time wind speed data to determine whether to curtail the turbines or not. Because the system curtails only when bats are present and thus at risk of fatality, the amount of curtailment is lower than under a more generalized blanket curtailment approach based solely on wind speed data.

Success of the EchoSense system is measured on two axes. Firstly, an ecological axis, defined by the reduction in fatalities associated with the EchoSense system as compared to a blanket curtailment strategy. Secondly, a financial axis, defined by the financial benefit of the EchoSense system compared with blanket curtailment in terms of gain of annual energy production (“AEP”) due to curtailment while accounting for installation and operational costs.

Here we present a two-year case study, funded by the United States Department of Energy (“DOE”), in which we examine the efficacy of the EchoSense smart-curtailment system compared to a blanket curtailment method, and, in the first year, a control treatment.

The twin goals of the first year of this study, according to the Statement of Project Objectives, were to demonstrate a 50% reduction in bat fatalities associated with EchoSense compared to the control while simultaneously reducing energy loss associated with the minimization by 50% compared to blanket curtailment (Appendix C) [Protected]. In 2019, the site was operated under a 6.9 m/s blanket curtailment, as agreed with the US Fish and Wildlife Service in response to the potential risk to Indiana bats (*Myotis sodalis*), so this cut-in speed was agreed upon for the study. The original goal of a 50%

reduction in bat fatalities was based on knowledge that bat activity is generally low at wind speeds of 6 m/s and above (Arnett et al. 2011). However, suitability analysis carried out for the study site at the 6.9 m/s cut-in wind speed agreed for turbine curtailment suggested that the reduction in fatalities would be less than 50% lower than the control for both the blanket and EchoSense curtailed turbines. The measure of success for EchoSense curtailment should therefore be its comparability to the reduction in bat fatalities associated with the blanket curtailment treatment.

In the second year, the cut-in wind speed for the curtailment was dropped to 5 m/s because of a shift in Incidental Take Permit ("ITP") requirements, and the number of treatments was reduced from three to two as a result in a reduction in the land available for use during the studies (Appendix D) [Protected]. The goal of the second year of the study was therefore to achieve an equivalent fatality rate between blanket and EchoSense curtailment treatments and at least a 50% reduction in AEP loss (Appendix D) [Protected].

3. Methods

3.1. Study area

The work was carried out at the English Farms Wind Project, owned by Alliant Energy, and located southeast of Montezuma, Iowa in Poweshiek County. This 170 MW facility comprises a total of 69 wind turbines including eleven 2.3 MW, 116-meter rotor diameter turbines and fifty-eight 2.5 MW, 127-meter rotor diameter turbines. Hub heights are 80 meters for 2.3 MW turbines and 88.6 meters for 2.5 MW turbines. The manufacturer's cut-in speed for both models is 3.0 m/s.

English Farms encompasses approximately 19,675 acres. The land is predominately composed of agricultural lands (cropland and hay/pasture). Cropland is dominated by corn and soybeans. There is a scattering of upland and riparian woodlots as well as open water bodies (e.g., cattle ponds, streams) (Figure 3.1).

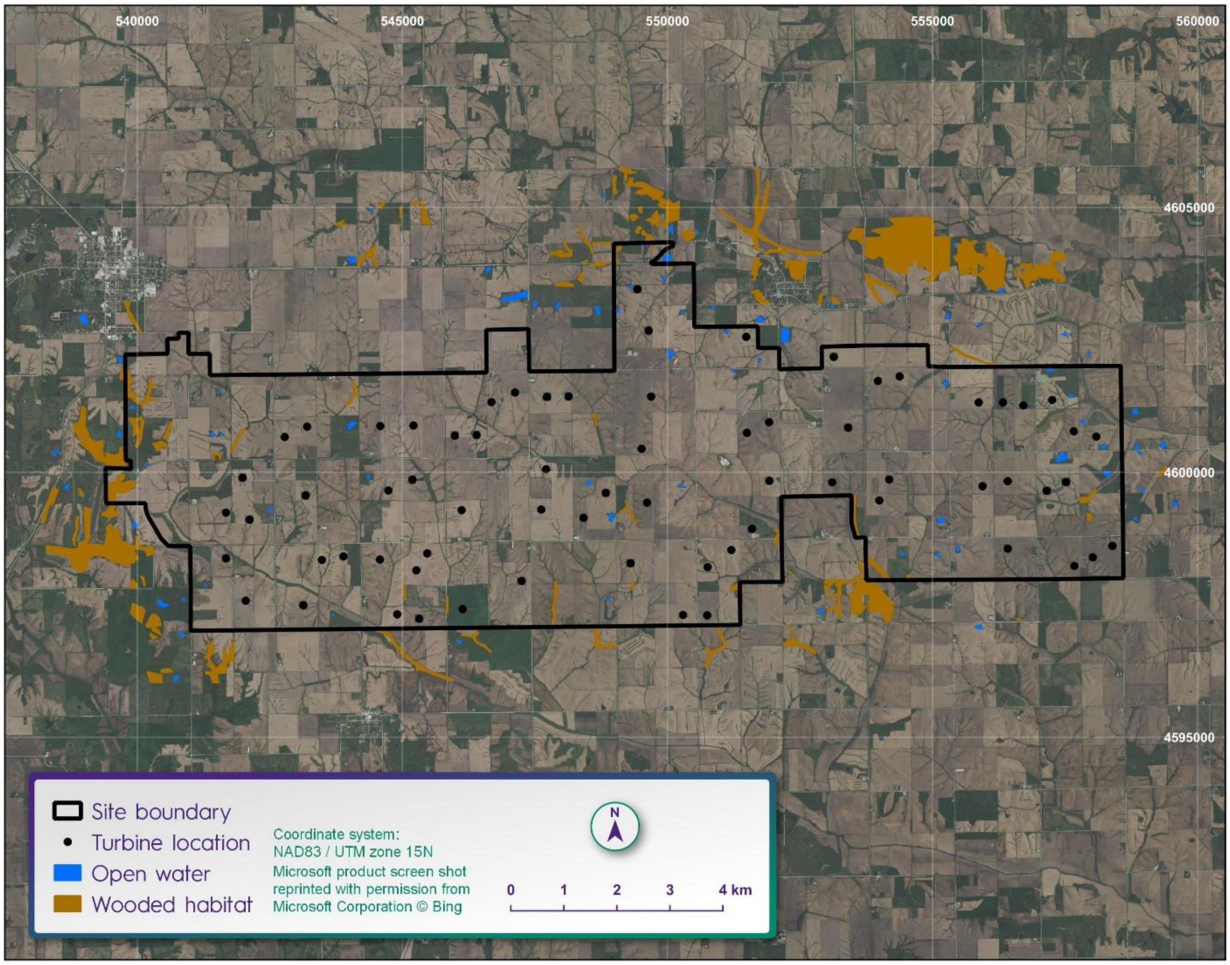


Figure 3.1: Land use around English Farms Wind Project

3.2. Installation of the EchoSense system

The EchoSense system was installed at English Farms between July 20 and August 3, 2020, and remained in situ for the duration of the two-year study (microphones and sensors were replaced at start of 2021 season). The EchoSense system consisted of bat acoustic detection units which were installed on the nacelles of 5 turbines spread across the site (see Figure 3.2 in Section 3.3) and a central server which communicated with the acoustic detectors and English Farm's SCADA (Supervisory Control and Data Acquisition) system, installed at the substation. The detector microphones were mounted on the top rear of the nacelles at approximately 80-88 meters high. Acoustic detectors were placed independently of the treatments to which turbines were assigned (i.e., turbines with detectors were not necessarily operated under EchoSense control). Detectors were located at the edges of the site and were positioned to minimize the distance between any given turbine and a bat detector (Figure 3.2; Figure 3.3). The bat acoustic data collected at the 5 turbines was used to determine whether the conditions for curtailment were met and if so, the curtailment action was pushed out to all turbines operating under EchoSense control. EchoSense is a flexible system which allows the use of bespoke curtailment threshold and action settings. In this case, the system was set up so that one or more bat detections at any of the deployed detectors at a wind speed of less than 6.9 m/s (in 2020) or 5 m/s (in 2021) would trigger a 30-minute curtailment period across all turbines operated under EchoSense control. If no bat activity was detected during the final ten minutes of the curtailment period, turbines resumed normal operation. If bat activity was detected in the final ten minutes, the curtailment period was extended for a further ten minutes until a 10-minute curtailment increment was free from bat detections at which point normal operation would resume.

3.3. Study design

All 69 turbines were planned to be included in the study. Turbines were curtailed from Aug 4 to Oct 15 (80 nights) in 2020 and from Aug 4 to Oct 15 (80 nights) in 2021, within a nightly curtailment window of one-half hour before sunset to one-half hour after sunrise. This time corresponds to the period of maximum exposure and fatality for bats at English Farms (Alliant Energy, 2020) and the period during which curtailment is anticipated to be most effective as a long-term minimization strategy.

Two types of search plots were used at the study site: full plot, and road and pad. Full plots consisted of a 160 m square plot centered on the turbine bases in 2020 and a 120 m square plot centered on the turbine bases in 2021. Full plots were mowed once every 9 days immediately following a search to provide reasonable visibility throughout the study. During searches, searchers walked 6 m spaced transects covering the entire plot. This distance was chosen to ensure that surveyors would have good visual coverage over the 100% of the area within the plot. In 2020, 28 turbines were surveyed according to the full plot methodology (25 of the 2.5 MW turbines and 4 of the 2.3 MW turbines). Three of the full plots were of reduced size (between 15 and 25% smaller) due to access restrictions. In 2021, 20 turbines were surveyed according to the full plot methodology (16 of the 2.5 MW turbines and 4 of the 2.3 MW turbines).

The remaining turbines (41 representing 34 of the 2.5 MW turbines and 7 of the 2.3 MW turbines in 2020 and 49 representing 42 of the 2.5 MW turbines and 7 of the 2.3 MW turbines in 2021) were surveyed according to the road and pad methodology. During road and pad searches, searchers walked along the edges of the roads and pads and scanned these areas for carcasses. Road and pad search plots extended further from the turbines than the full plots (160 m vs 60 – 80 m from the turbine tower), but a much smaller portion of the 160 m radius area was searched. Although these searches do not cover as great an area, they allow for investigation of fall distribution out to a greater distance and therefore estimation of the proportion of carcasses falling outside of the full plots.

3.3.1. 2020 study design

In 2020, the turbines were assigned to the following three treatment groups: control (standard turbine operation – turbine blades pitched out below manufacturers cut-in speed of 3.0 m/s), blanket curtailment (turbine blades pitched out below 6.9 m/s) and EchoSense curtailment (turbine blades pitched out below 6.9 m/s when bats were recorded at any of the five nacelle-mounted acoustic detectors). Twenty-three turbines were assigned to each group according to a spatially balanced, stratified random design to ensure that selected turbines provided a representative sample of the facility. Stratification variables were turbine type (2.3 vs. 2.5 MW), plot type (full vs. road and pad), 2019 mortality (turbines at which three or more carcasses were detected in 2019 were classified as higher fatality and treated as a separate stratum), and spatial distribution across the site. Additionally, one of the three full plots of reduced size were assigned to each of the three treatments (Table 3.1). Due to the relatively homogeneous nature of the site, we did not stratify by habitat type.

In practice however, several turbines needed to be removed from the analysis due to extensive downtime during the study period (8 turbines) or due to the operation changing from one treatment to another during the study period (2 turbines). The reason behind the former was not disclosed by the site operators, and the latter was the result of human error. In addition, one turbine that had been planned to be operated under blanket curtailment was operated under the control conditions, again, due to human error and was included in the analysis according to the conditions under which it was actually operated. Planned and realized sample sizes among plot type, turbine size and treatment are presented in Table 3.1 and Table 3.2 below and the final spatial layout of the treatments and plot types is shown in Figure 3.2.

Table 3.1: Number of turbines included in each combination of treatment and plot type in 2020. Numbers in parentheses represent planned sample sizes.

Number of turbines	Full plot	Road and pad	Total
Control	9 (10)	13 (13)	22 (23)
Blanket curtailment	7 (9)	12 (14)	19 (23)
EchoSense curtailment	6 (9)	12 (14)	18 (23)
Total	**22 (28)**	**37 (41)**	**59 (69)**

Table 3.2: Number of turbines included in each combination of treatment and turbine size in 2020. Numbers in parentheses represent planned sample sizes.

Number of turbines	2.5 MW turbines	2.3 MW turbines	Total
Control	18 (19)	4 (4)	22 (23)
Blanket curtailment	16 (20)	3 (3)	19 (23)
EchoSense curtailment	14 (19)	4 (4)	18 (23)
Total	**48 (58)**	**11 (11)**	**59 (69)**

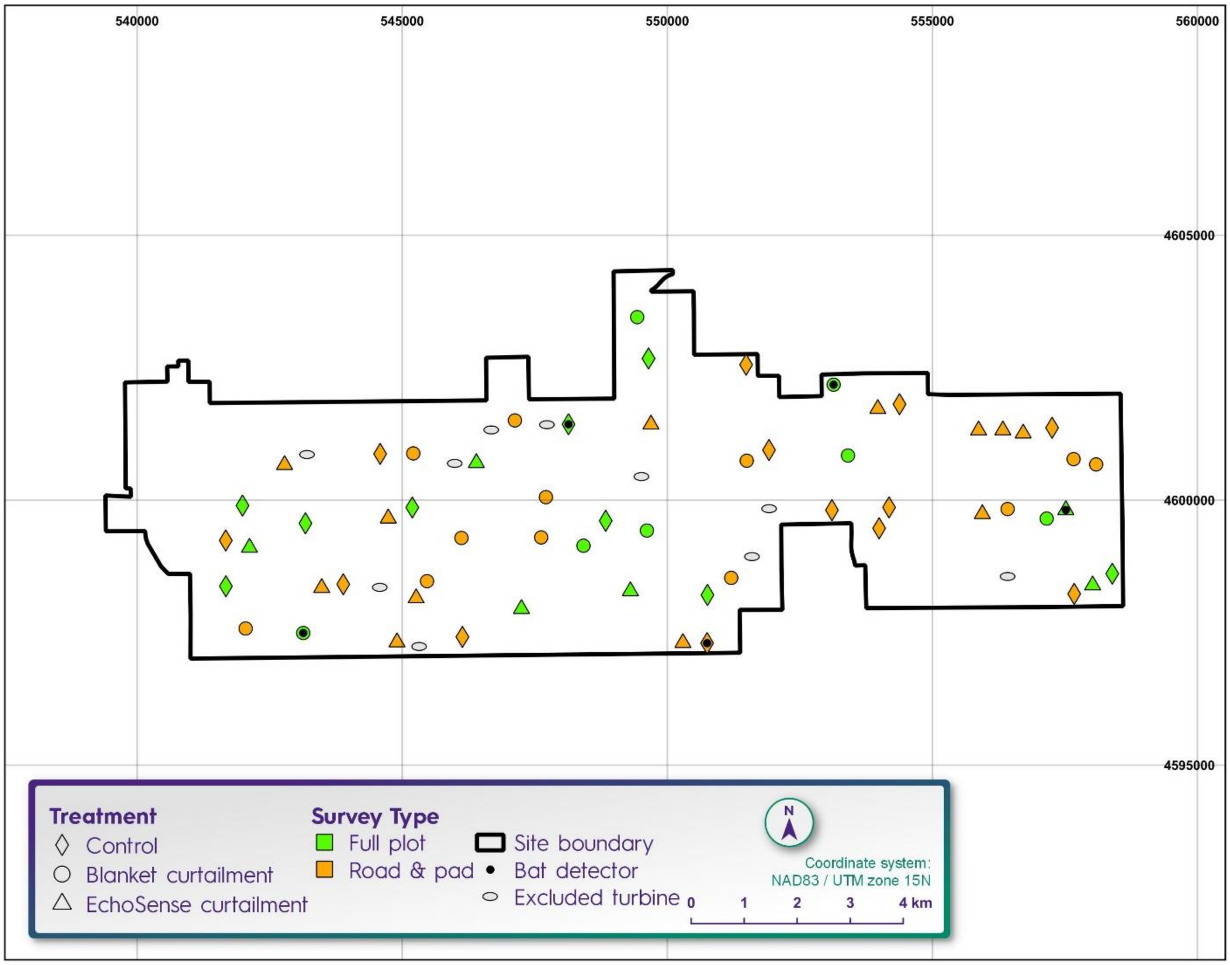


Figure 3.2: **Spatial layout of treatment type and plot type in 2020. Location of bat detectors linked to the EchoSense system are also indicated.**

3.3.2. 2021 study design

In 2021, the turbines were assigned to two treatment groups: blanket curtailment (turbines blades are pitched out below 5.0 m/s) and EchoSense curtailment (turbine blades are pitched out below 5.0 m/s when bats are present in the rotor swept area). Thirty-five and thirty-four turbines respectively were assigned to each group according to a spatially balanced, stratified random design as for 2020 (see section 3.3.1).

However, two turbines were removed from the bat fatality and energy yield analysis and a further six from just the energy yield analysis due to extensive downtime during the study period. A higher threshold for maximum turbine downtime was implemented for the energy yield analysis to avoid the results of that analysis relying too much on simulated rather than measured production data. An additional eleven turbines were also removed from both analyses as they were operated under incorrect curtailment settings (6.9 m/s rather than 5 m/s wind speed cut-in) throughout August. As before, the reason behind the former was not disclosed by the site operators, and the latter was the result of human error. Planned and realized numbers of turbines assigned to each treatment by plot type and turbine size are presented in Table 3.3 and Table 3.4. The final spatial layout of the treatments and plot types is shown in Figure 3.3.

Table 3.3: Number of turbines included in each combination of treatment and plot type for the analysis of bat fatalities in 2021. Numbers in parentheses represent planned sample sizes.

Number of turbines	Full plot	Road and pad	Total
Blanket curtailment	7 (10)	22 (25)	29 (35)
EchoSense curtailment	8 (10)	19 (24)	27 (34)
Total	**15 (20)**	**41 (49)**	**56 (69)**

Table 3.4: Number of turbines included in each combination of treatment and turbine size in 2021. Numbers before the forward slash represent sample sizes for the analysis of fatalities and numbers after the forward slash represent sample sizes for the energy yield analysis. Numbers in parentheses represent planned sample sizes.

Number of turbines	2.5 MW turbines	2.3 MW turbines	Total
Blanket curtailment	23/20 (29)	6/6 (6)	29/26 (35)
EchoSense curtailment	24/21 (29)	3/3 (5)	27/24 (34)
Total	**47/41 (58)**	**9/9 (11)**	**56/50 (69)**

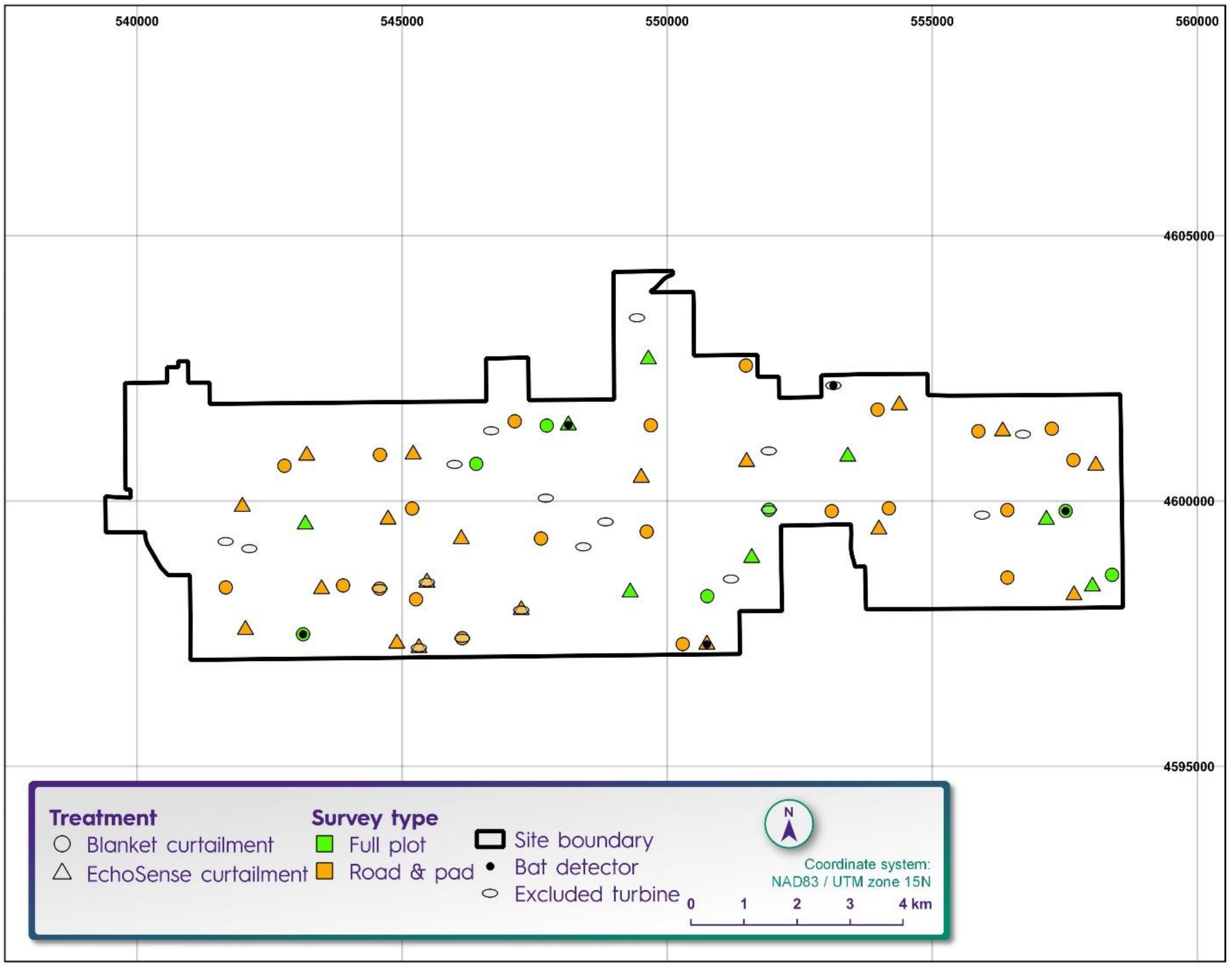


Figure 3.3: **Spatial layout of treatment type and plot type in 2021. Points with both a treatment and an excluded turbine symbol were included for the fatality analysis but excluded for the energy yield analysis. Location of bat detectors linked to the EchoSense system are also indicated.**

3.4. Carcass searches

Carcass searches were conducted at each plot every three days from August 4th to October 16th, 2020 and from July 31st to October 17th, 2021. The plots were systematically searched, and all detected bat carcasses were recorded. A range of information was recorded regarding each detection including the date, the species, the exact location, the associated turbine, and the plot type being surveyed. A visibility class for the area of ground within which the carcass was detected was also recorded based on the scale developed for the 2019 operational monitoring carried out prior to this study (Alliant Energy, 2020). Visibility classes used were:

- Easy: more than 90% bare ground; sparse vegetation less than 6 inches tall

- Moderate: more than 25% bare ground, vegetation less than 6 inches tall and mostly sparse
- Difficult: less than 25% bare ground, less than 25% ground cover is more than 12 inches tall, or ground conditions are rocky/scrubby
- Very difficult: less than 25% bare ground, more than 25% of vegetation is more than 12 inches tall or rock/scrub)

Carcasses were removed immediately following detection.

3.5. Bias trials

Bias trials were carried out to estimate the number of fatalities that occurred during the study. These included two types of trials: searcher efficiency trials and carcass persistence trials.

Searcher efficiency trials were carried out to estimate the probability of bat carcasses being detected by searchers. In 2020, three searchers carried out fatality searches. For each of these, ten fresh bat carcasses were placed across the search areas (split equally between road and pad, and full plots) over two dates. In 2021, only two searchers carried out fatality searches. For these, 31 (23 on full plots and eight on road and pads) and 29 (23 on full plots and six on road and pads) fresh bat carcasses respectively were placed across the search areas over two dates. The person placing the carcasses did not inform searchers when a trial was being conducted. Carcasses were placed such that their locations were representative of the conditions under which carcasses might occur. Carcasses were placed prior to, but on the same day as a scheduled carcass survey and were discreetly marked to identify them as trial carcasses when found. These carcasses were left in situ for carcass persistence trials (see below). Immediately following the search, the number of carcasses available for detection during the trial (i.e., that were not removed by scavengers before searchers could search for them) was determined by the person responsible for placing the carcasses. Carcasses used for searcher efficiency trials included five species – big brown bat (*Eptesicus fuscus*), eastern red bat (*Lasiurus borealis*), evening bat (*Nycticeius humeralis*), hoary bat (*Lasiurus cinereus*), and silver-haired bat (*Lasionycteris noctivagans*).

Carcass persistence trials were carried out in both years to estimate the average length of time a carcass was available for detection in the field. The same carcasses were used for carcass persistence trials as for searcher efficiency trials (see above). Trial carcasses were monitored for 14 days, on days 1, 2, 3, 4, 7, 10, and 14 after placement. At the end of the 14-day period, any remaining evidence of the carcass was removed. If a mowing event occurred during the carcass persistence trial the carcasses were temporarily removed and then replaced after the mowing was complete.

3.6. Area correction

It was assumed that all bat carcasses fall within the 160 m radius covered for road and pad plots. Therefore, a density weighted proportion ("DWP") could be calculated to correct for the number of carcasses falling outside of the searched area of each plot based on the area of the total potential fall zone searched and the distribution of carcasses within that fall zone as a function of distance to the turbine. DWP for each turbine was calculated using the ring method. Carcasses across all turbines are pooled and assigned to 10 m intervals rings determined by their distance from the nearest turbine. The number of carcasses in each ring was then standardized using the proportion of the total area within each ring that was searched (also across all turbines). Standardized carcass number was then summed and the fraction of that sum falling within each ring was calculated to give the expected distribution of carcasses across the rings for the entire site.

For each turbine, the proportion of the total area within each ring that was searched was multiplied by the overall proportion of carcasses expected to fall within each ring and summed to give the Density Weighted Proportion for that turbine. (See equation below where X_i = the number of carcasses in ring *I*, and *a* = the fraction of the ground searched in each ring).

$$DWP = \sum_i X_i \,/ \sum_i \widehat{M}\,rel_i$$

$$\widehat{M}_{rel} \quad = \quad X/a$$

Although the distribution of carcasses relative to turbines may be different among 2.3 MW and 2.5 MW turbines and potentially also among treatment types since the wind profile in the time during which collisions might occur will differ, insufficient data were available to allow separate analyses based on turbine size or treatment type. Data were therefore pooled across both turbine types and all treatments for calculation of DWP.

3.7. Statistical analysis of fatality data

Overall number of bat fatalities at the site during the study period were estimated using GenEst (Simonis et al. 2018). GenEst is software that can be used to estimate carcass detection rates from bias trial data and uses this, alongside carcass search data, to generate predictions of total numbers of fatalities with an associated measure of precision (Simonis et al. 2018). All turbines were included in this analysis as the aim was to estimate the realized number of fatalities on site during the two years. Searcher efficiency was estimated by using maximum likelihood, under the assumption that carcasses missed during the first search following their arrival will not be detected in subsequent searches (k = 0). Plot type was included as a candidate covariate and AICc (a variant of Akaike's Information Criterion ("AIC"), a measure of the relative quality of statistical models, that is appropriate for a small sample size) scores were used to select the most parsimonious model to carry forward for fatality estimation. Plot type was assumed to be related to visibility class. However, if plot type was not selected in the most parsimonious model, visibility class was included as a candidate covariate instead. Similarly, carcass persistence was modelled using plot type as a candidate covariate and fit using one of four possible distributions (exponential, Weibull, lognormal or loglogistic). AICc scores were used to select among models as above. Carcass persistence and searcher efficiency models were then used in combination with the turbine specific DWP calculated as described in Section 3.6, to estimate the total number of fatalities that occurred at the English Farms site over the study period, as well as the rate of fatalities per MW and per turbine.

To investigate potential differences in bat fatality rate associated with treatment type, a generalized linear model with a Poisson error structure was fit to the raw fatality data using R version 4.0.2 (R Core Team, 2020). For 2020, this analysis was carried out only for the 59 turbines that were operated under a single curtailment regime throughout the study period and that did not include significant periods of downtime (see Section 3.3.1). In addition, carcasses detected between September 7th and September 14th at all turbines were also removed because EchoSense turbines were not operating under the

EchoSense curtailment regime during these periods. For 2021, the analysis included 56 turbines operated under a single curtailment regime throughout the study period and without significant periods of downtime. Although there were days when the EchoSense system was not operating as expected (e.g., due to microphone failures), these were treated as representative of the realized operation of the system in the field (although noted and investigated to facilitate more consistent operation of the system in future), therefore data for all dates were included for 2021. Carcass counts per turbine were modelled as a function of plot type (full plot searches versus road and pad searches), turbine size (2.3 MW versus 2.5 MW) and treatment (blanket curtailment, EchoSense curtailment or control). An offset was used to account for the variation in detection probability among turbines arising from carcass persistence, searcher efficiency, reduced operational time and the proportion of carcasses falling outside of the searched area (DWP). The offset was calculated as:

$$Offset = P_{op} \times DWP \times r_3 \times p$$

where P_{op} is the proportion of time that the turbine was operational during the survey period (1 – proportion of downtime excluding downtime associated with curtailment), *DWP* is the probability that the carcass falls within the searched area, r_3 is the probability that a carcass that arrived during the 3-day search interval would be present at the end of the interval (calculated within GenEst from the carcass persistence trials data) and p is the probability of detection by the searcher (calculated within GenEst from the searcher efficiency trials data). Searcher efficiency rates based on visibility class could not be adequately incorporated during this step so the estimate from the null model was used.

Model validation was carried out to check for overdispersion, influential data points, any patterns in the residuals that could suggest systematic bias or incorrect modelling of parameters, and any residual spatial correlation. Hypothesis testing was used to assess the statistical significance of parameters used in the model, with p-values calculated using a Chi-squared analysis of deviance for single term deletions.

3.8. Energy yield assessment

Energy yield assessment was carried out only for 59 and 50 turbines in 2020 and 2021 respectively that were operated under a single curtailment regime throughout the study period and that did not include significant periods of downtime. See Section 3.3 for details on the breakdown of turbines for each curtailment regime and Appendix E [Protected] for the breakdown of turbines considered and hours of curtailment and availability.

To estimate the lost energy associated with any curtailment, a set of reference power curves (representing power output by wind speed) were generated for each turbine. These were then used to estimate the lost production during periods of curtailment. Data were cleaned and reference power curves generated using an industry standard approach described below:

1. Using provided turbine event/fault and status logs, any periods of downtime were removed from the reference power curve dataset. As part of this step, downtime associated with curtailment was separated from other sources of turbine availability in order to later quantify the lost production attributable solely to curtailment based on the provided event/fault logs and analysis of pitch angle and rotor speed relationships, sunrise/sunset data, turbine status, and analysis of production vs wind speed during periods of curtailment and non-curtailment.

2. Measured nacelle wind speeds were density adjusted using the density from the nearest ERA5 reference node (ECMWF, 2020).
3. Sector-wise deviations in performance were assessed to determine if sector-wise reference power curves were necessary. Sector-wise deviations in turbine performance were minimal, meaning a single reference power curve for each turbine was suitable to characterize the relationship between nacelle measured wind speed and turbine production. In other words, while turbines experience directional wind speed variability due to wake effects, the empirical relationship between nacelle measured wind speed and production were unaffected by wake effects as they are inherent within the nacelle measured wind speed. However, this does mean that turbines experiencing lower wind speeds due to wakes may experience more curtailment because they spend more time below the cut-in wind speed as a result of the wake reduced wind speed.
4. Since wind speed data collected at the turbine can be affected by turbulence from the rotor itself, wind speed was validated by regressing wind speed from the nacelle-mounted anemometers against data collected at hub-height from a fixed meteorological ("met") mast during operational and non-operational periods. SCADA data were filtered using the provided fault states for each timestamp, rotor speed, pitch angle, and active power signals to determine if the turbine was operating or not during the timestamp. Linear regressions were then performed on an individual turbine basis to model the relationship between the met tower and the nacelle-measured wind speed separately for operational and non-operational periods, excluding any waked periods where the met mast was impacted by the nearby turbines as per the IEC power performance measurement standard (61400-12-1, 2017). Next, the non-operational relationship was regressed on an individual turbine basis against the operational relationship to generate a correction used to better align non-operational datasets with the wind speeds in the operational dataset. Applying this correction reduces the nacelle measured wind speeds during non-operational wind speeds when regressions are strong. However, Natural Power notes that there is additional uncertainty in using this approach as it relies on met data that can be more than 8 km from some turbines, and some turbines were unable to be corrected using this method due poor regressions with the permanent met mast. Additionally, insufficient data was available on a sector wise basis during non-operational periods (less than 50 data points for every sector) to quantify wind direction-dependent wake effects and resulting bias corrections, therefore derived corrections were independent of wind direction. For the 2020 dataset, the regressions were strong enough ($R^2>0.8$) for a subset of turbines within 3km of the met tower to be corrected, while in the 2021 dataset regressions were reduced substantially due to anemometer degradation at the permanent met mast. Therefore, Natural Power utilized the corrections derived from the 2020 dataset to correct for rotor effects experienced in 2021, where applicable. Natural Power performed a sensitivity analysis on the periods corrected for non-operational periods and those that were unable to be corrected and accounted for this in the uncertainty quantification and notes that the overall

change due to these corrections in the estimated curtailment losses as a percentage of AEP during non-operational periods was an order of magnitude smaller than the quantified overall loss uncertainty, and therefore considers these corrections to not be substantially impactful on the overall loss estimates presented in this report.

The reference power curves were then used to calculate a theoretical power output during periods identified as being unavailable based on the steps/criteria outlined above.

For periods when turbines were curtailed because of the minimization strategy, the nacelle measured wind speed and the derived individual operational power curve were used to estimate the theoretical production during the curtailed period, and thus quantify the estimated lost production.

Lost production arising due to curtailment was calculated as the difference between the actual SCADA measured production during the curtailment period and the theoretical production as calculated using the reference power curve for each turbine. To estimate the effect on annualized energy production ("AEP") for each year, the total production at each individual turbine for the full year of data from 2020 were calculated and compared against the estimated lost production due to curtailment over each period of record ("POR"). Some turbines experienced extensive downtime over the curtailment POR due to reasons unrelated to curtailment and were therefore excluded from the study. For turbines which experienced excessive downtime over the full 2020 period that was used to derive each turbine's estimated annual production but exhibited sufficient availability over the 2020 or 2021 curtailment POR, the average AEP of all turbines in its respective treatment group was used as the basis for that turbine's estimated AEP. The variability of AEP between turbines with similar availability was approximately 10%, which correspondingly increased the uncertainty of the percentage curtailment of AEP estimates presented in Section 4.1.3.

In order to quantify uncertainty, Natural Power combined uncertainty in quadrature as described in section 8 of the industry technical standard for wind plant power performance (TR-1-2021, 2021) and the International Bureau of Weights and Measurements (BIPM, 2008). The combined uncertainty, σ_{total}, can be calculated as the square root of the combined variance of each uncertainty component, σ_i, as shown in the equation below, assuming all uncertainty components are uncorrelated:

$$\sigma_{total} = \sqrt{\sum_{i=1}^{n} \sigma_i^2}$$

The following uncertainty components were considered:

- Nacelle measured wind speed calibration uncertainty
- Permanent met tower wind speed calibration uncertainty
- Operational vs non-operational WS bias correction uncertainty
- Energy metering uncertainty
- 1-year interannual variability of curtailment loss due to wind speed inter-annual variability
- Data normalization uncertainty of synthesizing turbine production

Natural Power notes that if a turbine is curtailed, its wake impacts on wind speed will be reduced for other turbines still in operation nearby, thereby providing some positive benefit in production to nearby turbines. However, quantifying the potential benefit of this is extremely challenging as it would require a time series assessment of wake losses on an individual turbine basis for the numerous permutations of plant wide curtailment over the assessed POR. Additionally, while turbines may not be operational during curtailment, there are downwind effects on wind speed that are challenging to model due to the effects of the tower and rotor even when not in operation.

Nearby wind plants such as the North English and North English II wind farms externally wake the English Farms project. These external wake effects are inherent within the measured nacelle wind speeds and SCADA production and therefore their effects are inherent within the AEP evaluations considered in this assessment. A detailed assessment of external wake impact from these projects was not considered within the scope of this analysis.

Hysteresis effects arise from the fact that turbine control considerations require a wind speed buffer from the cut-in wind speed such that if wind speeds are near the cut-in wind speed the turbine is not switching between operational and non-operational states excessively. This wind speed buffer leads to times where the turbine may be curtailed above the specified cut-in if the turbine was curtailed in the prior 10-minute period, thus resulting in a hysteresis effect. In the 2020 data, we noted that hysteresis effects resulted in periods of curtailment up to 7.5 m/s (10-minute average wind speed) for the 6.9 m/s blanket and 6.9 m/s EchoSense treatment groups and therefore included any additional lost energy associated with this behavior in the energy calculations. Similarly, for the 3.0 m/s control group, there was a non-zero loss estimated due to periods of curtailment where the nacelle measured wind speed was greater than 3.0 m/s but the turbine was curtailed. In the 2021 data, the hysteresis effects were apparent up to 5.5 m/s for both the blanket 5.0 m/s and the 5.0 m/s EchoSense treatment groups. This phenomenon is likely due to operational hysteresis effects and averaging wind speeds into 10-minute periods, meaning curtailment may be applied for a 10-minute timestamp even though the average wind speed of that period is greater than cut-in wind speed because the curtailment is not based on a rolling 10-minute average, but instead the most recent 10-minute period. Due to the 10-minute resolution of the SCADA data, Natural Power was unable to assess the hysteresis and operational implementation effects for intervals less than 10-minutes as Natural Power was provided with minimal details on the implementation strategy around hysteresis and the decision framework for the blanket and control treatment groups. This phenomenon is one of the contributing causes to the errors in AEP loss estimated by the pre-implementation suitability analysis discussed in section 4.1.4.

Results of the energy yield assessment are presented in Section 4.1.3 and Section 4.2.3 and in Table 4.7 and Table 4.16. Appendix E [PROTECTED] provides a detailed look at turbine specific available, curtailed, and downtime hours for each treatment group and year.

3.9. Statistical analysis of energy loss data

A generalized linear model (GLM) with a Gamma error structure and log link was fit to the data reflecting energy loss due to curtailment using R version 4.0.2 (R Core Team, 2020). A Gamma structure was selected as it is suitable for modelling continuous data that is bounded at 0 (since realized energy yield will not exceed maximum theoretical yield). For 2020, this analysis was carried out only for the 59 turbines that were operated under a single curtailment regime throughout the study period and that did not include significant periods of downtime (see Section 3.3.1). For 2021, the analysis included 50 turbines operated under a single curtailment regime throughout the study period and without significant periods of downtime. Predicted curtailment-related energy loss per turbine (in MWh) was modelled as a function of turbine size (2.3 MW versus 2.5 MW) and treatment (blanket curtailment, EchoSense curtailment or control). An offset was used to account for the effects of reduced operational time.

Model validation was carried out to check for influential data points, any patterns in the residuals that could suggest systematic bias or incorrect modelling of parameters, and any residual spatial correlation. Hypothesis testing was used to assess the statistical significance of covariates (turbine size and curtailment treatment) used in the model, with *p*-values calculated using Chi-squared analysis of deviance for single term deletions.

For 2020, Tukey's method for multiple comparisons was used to calculate *p*-values for each pair of curtailment treatments in order to determine whether energy loss per turbine differed significantly among treatments.

4. Results

4.1. 2020 results

4.1.1. Fatality estimation for 2020

A total of 241 bat carcasses were recovered during carcass surveys, 100 of which were associated with turbines operating under control conditions, 59 were associated with turbines operating under blanket curtailment and 64 with turbines associated with EchoSense curtailment respectively (see Table 4.1). The carcasses were primarily eastern red bat (*Lasiurus borealis*) (109), silver-haired bat (*Lasionycteris noctivagans*) (61), hoary bat (*Lasiurus cinereus*) (46) and big brown bat (*Eptesicus fuscus*) (22). One federally endangered species carcass, Indiana bat (*Myotis sodalis*), was detected during the fatality surveys, at a control turbine.

Table 4.1: Carcasses detected at English Farms during standardized carcass searches in 2020

Species	Control (3 m/s cut-in wind speed) N = 22	Blanket curtailment (6.9 m/s cut-in wind speed) N = 19	EchoSense (6.9 m/s cut-in wind speed and bat activity) N = 18	Carcasses found at turbines removed from study N = 10	Total N = 69
Eastern red bat (*Lasiurus borealis*)	36	26	35	12	**109**
Silver-haired bat (*Lasionycteris noctivagans*)	27	17	15	2	**61**
Hoary bat (*Lasiurus cinereus*)	25	10	8	3	**46**
Big brown bat (*Eptesicus fuscus*)	10	6	6	0	**22**
Indiana bat (*Myotis sodalis*)	1	0	0	0	**1**
Evening bat (*Nycticeius humeralis*)	1	0	0	0	**1**

Tricolored bat (*Perimyotis subflavus*)	0	0	0	1	**1**
Total*	**100 (4.55)**	**59 (3.11)**	**64 (3.56)**	**18 (1.80)**	**241 (3.49)**

**Number in parentheses is average per turbine*

Searcher efficiency was estimated based on data from 30 bat carcasses placed out for detection by searchers: 15 at full plots and 15 at road and pad plots. AICc scores from the models fitted indicated that the most parsimonious model included plot size as a covariate (change in AICc (ΔAICc) between the intercept-only and the model including plot type = 1.18). Searcher efficiency estimates are presented in Table 4.2.

Table 4.2: Searcher efficiency estimates from GenEst for 2020

Plot type	Number of carcasses available for detection	Number of carcasses detected	Estimated searcher efficiency (median and 90% CIs)
Full plot	15	12	0.80 (0.58 – 0.92)
Road and pad	15	15	0.97 (0.85 – 0.99)

Carcass persistence time was estimated based on data from 30 bat carcasses, 15 of which were placed at full plots and the remaining 15, at road and pad plots. The lowest AICc score was associated with an exponential model with no explanatory covariates, however, the difference in AICc values between this and a Weibull model with plot type as an explanatory covariate was small (0.9). Since models with a difference in AIC of less than 2 can be considered to have similar levels of support, and plot type is expected to affect persistence time (with carcasses on roads and pads likely to be more detectable to scavengers than in full plots), this model was taken forwards for the fatality estimation. Carcass persistence estimates are presented in Table 4.3.

Table 4.3: Carcass persistence estimates from GenEst for 2020, modelled using a Weibull distribution with plot type as an explanatory covariate

Plot type	Number of carcasses	Estimated persistence time (median and 90% CIs)	Probability that a carcass is present at the end of the 3-day search interval (r3) (median and 90% CIs)
Full plot	15	3.56 (2.45 – 5.07)	0.80 (0.67 – 0.91)
Road and pad	15	2.73 (1.73 – 3.97)	0.66 (0.55 – 0.77)

Detection probability and DWP calculated for turbines of each plot type is shown in Table 4.4.

Table 4.4: Estimated detection probabilities as provided by GenEst and with incorporation DWP for 2020

Plot type	DWP (Mean and 90% CIs)	GenEst detection probability (median and 5 and 95% quantiles)	Detection probability adjusted for DWP of area (median and 5 and 95% quantiles)
Full plot	0.53 (0.52 – 0.54)	0.63 (0.44 – 0.78)	0.34 (0.33 – 0.34)
Road and pad	0.05 (0.03 – 0.07)	0.62 (0.50 – 0.74)	0.03 (0.02 – 0.05)

The total estimated mortality for the site during the survey period and the estimated mortality per MW and per turbine are presented in Table 4.5.

Table 4.5: Estimated number of bat fatalities that occurred at English Farms during the 2020 study period. This number is also presented per MW and per turbine (calculated as total fatalities divided by the nameplate energy generation of 170 MW and 69 turbines respectively)

	Total fatalities (90% cIs)	Fatalities per MW (90% CIs)	Fatalities per turbine per season (90% CIs)
English Farms	1959.7 (1515.0–- 2507.7)	11.5 (8.9–- 14.8)	28.4 (22.0–- 36.3)

4.1.2. Assessment of curtailment strategy effect

The raw number of carcasses found per turbine, standardized to account for differences in the proportion of time that the turbine was operational during the survey period, the DWP, the probability of a carcass persisting to the next search date and the searcher efficiency, are presented in Figure 4.1.

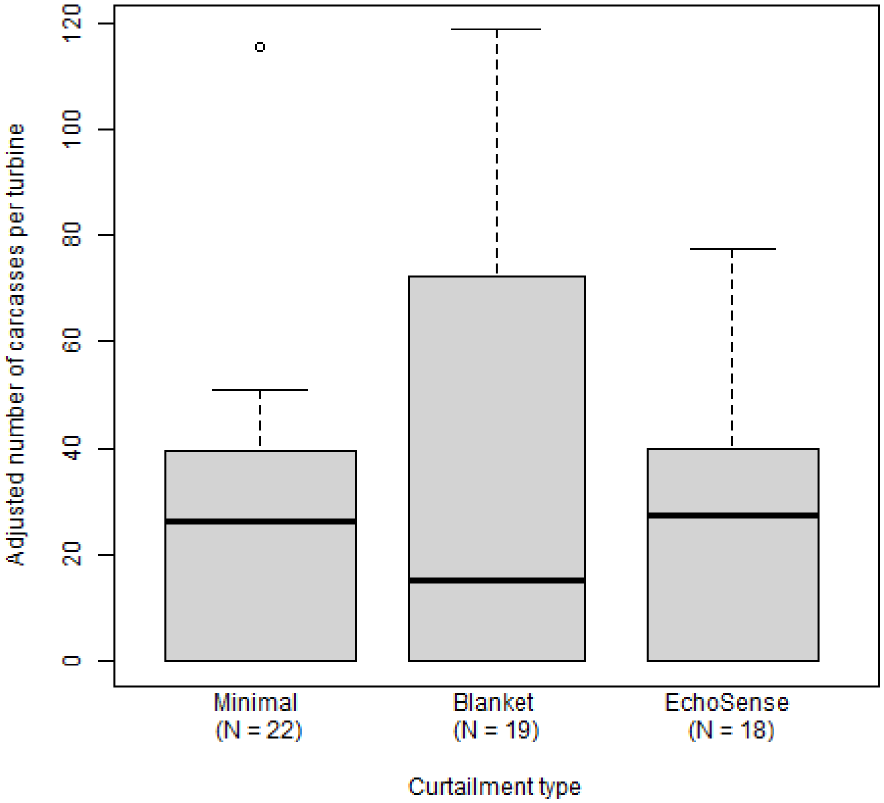


Figure 4.1: **Number of bat carcasses detected per turbine in 2020 adjusted for detection probability and turbine operational time. The thick line indicates the median fatality rate, the box represents the interquartile range (IQR; within which 50% of the data are found) and the whiskers represent the quartiles ±1.5 * IQR. Points beyond the whiskers may be considered to be outliers.**

A GLM with a Poisson error structure was fit to the data, with turbine size, plot type and treatment included as explanatory factor variables. Model validation indicated that the Poisson error structure was appropriate and that there was no residual spatial autocorrelation among the data points. No statistically significant effects were identified at a threshold of $p < 0.05$. However, all terms were retained in the final model. Parameter estimates and p-values for the model are presented in Table 4.6. There was no statistical support for differences among treatments. Due to the lack of support for the model, no post-hoc testing was carried out to further investigate differences among treatments.

Table 4.6: **Model parameters and p-values from a GLM used to predict the number of carcasses detected per turbine assuming a Poisson error structure.**

Parameter	Estimate (link scale)	Standard Error	X^2 statistic	Degrees of freedom	P-value
Intercept	3.209	0.118	-	-	-
Plot type (Roads and pads)	0.279	0.186	2.112	1	0.146
Treatment (Blanket)	-0.280	0.186	2.834	2	0.243
Treatment (EchoSense)	-0.045	0.166			
Turbine size (2.3 MW)	0.267	0.166	2.474	1	0.116

4.1.3. Energy yield

EchoSense curtailment was associated with an average 41% reduction in per turbine energy loss when compared to blanket curtailment (Table 4.7) for the 2020 POR. If applied across all 69 turbines at English Farms, EchoSense allowed for 5,490 MWh (13,358 MWh – 7,868 MWh) more production compared to blanket curtailment of 6.9 m/s.

To illustrate the differences in control groups, Appendix E [Protected] provides the individual turbine results for the full year of 2020 and presents the total number of hours each turbine was available to produce energy, the number of hours unavailable due to events not related to curtailment, and the number of hours each turbine was curtailed for each treatment group. The energy results presented in Table 4.7 use the nacelle measured wind speed at the time of curtailment and reference power curve discussed in section 3.8 to estimate the lost energy associated with each curtailment event. To calculate the AEP loss, the total production lost due to curtailment was compared against the total potential production for 2020, where total potential production is sum of the reported power and lost energy due to curtailment, on an individual turbine basis and then averaged for each treatment group.

Table 4.7: **Per turbine energy yield loss (compared to uncurtailed operation) associated with each 2020 treatment. Numbers in parentheses represent uncertainty (incorporating the standard errors associated with the wind speed analysis and the operational power curve).**

Treatment	Number of Turbines	Individual Turbine Average Curtailment Loss (% of AEP*, 90% CIs)	Min Curtailment Loss (% of AEP)	Max Curtailment Loss (% of AEP)	Individual Turbine Average Curtailment Loss (MWh**, 90% CIs)	Predicted Curtailment Loss Across 69 Turbines (MWh**)
Control (feather below 3.0 m/s)	22	0.14% (0.13% – 0.15%)	0.1%	0.2%	13.2 (12.2 – 14.2)	908.4
Blanket curtailment (6.9 m/s)	19	2.13% (2.03% – 2.23%)	1.2%	2.5%	193.6 (184.3 – 202.9)	13,358.1
EchoSense curtailment (6.9 m/s cut-in when bats present)	18	1.24% (1.19% – 1.29%)	1.0%	1.5%	114.0 (109.0 – 119.0)	7,868.6

**Annual Energy Production; **Megawatt hours*

4.1.4. Assessment of curtailment strategy effect on energy loss

The predicted curtailment-related energy loss per turbine, standardized to account for differences in the proportion of time that the turbine was operational during the survey period is presented in Figure 4.2.

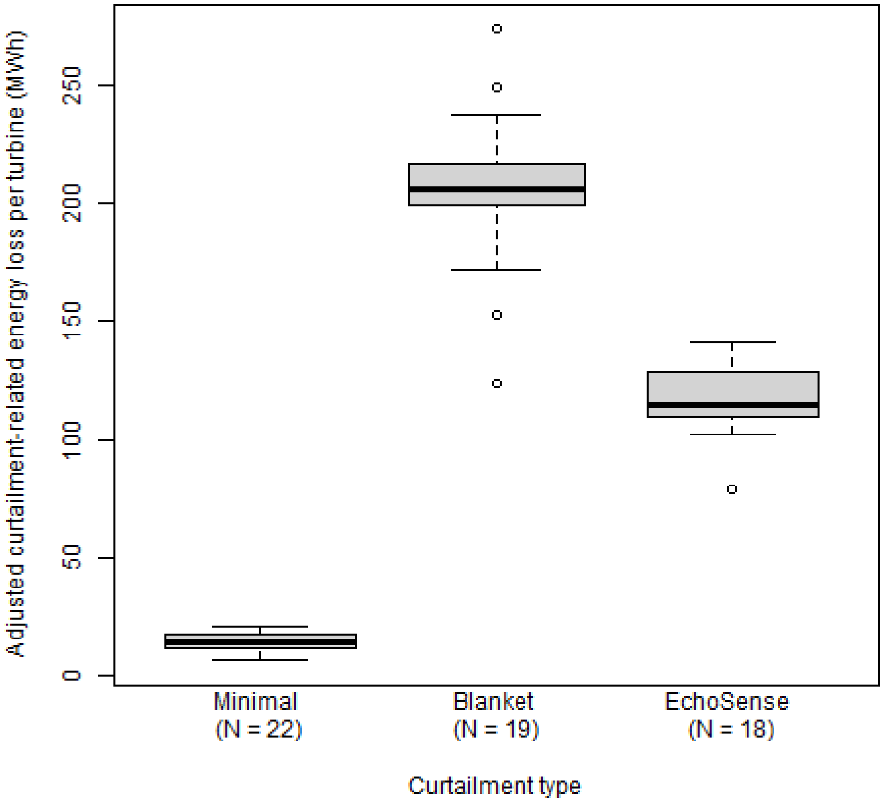


Figure 4.2: Predicted curtailment-related energy loss per turbine in 2020 adjusted for turbine operational time. The thick line indicates the median energy loss, the box represents the interquartile range (IQR; within which 50% of the data are found) and the whiskers represent the quartiles ±1.5 * IQR. Points beyond the whiskers may be considered to be outliers.

A GLM was fit to the data, with turbine size and treatment included as explanatory factor variables. Model validation indicated that the Gamma error structure was reasonable and that there was no residual spatial autocorrelation among the data points. Both curtailment treatment and turbine size predicted curtailment-related energy loss. Higher losses were associated with blanket curtailment compared to EchoSense curtailment and with EchoSense curtailment compared to minimal curtailment. Higher losses were also associated with larger turbines compared to the smaller turbines. All terms were retained in the final model. Parameter estimates and *p*-values for the model are presented in Table 4.8. There is strong support for an effect of the EchoSense system applied upon the energy loss resulting from curtailment ($p<0.001$). Tukey's multiple comparisons method provides support for a difference among each pair of curtailment strategies (Table 4.9).

Table 4.8: Model parameters and *p*-values from a GLM used to predict energy loss per turbine

Parameter	Estimate	Standard Error	X^2 statistic	Degrees of freedom	*P*-value
Intercept	2.667	0.043	-	-	-
Treatment (Blanket)	2.698	0.061	1625.78	2	<0.001
Treatment (EchoSense)	2.159	0.062			
Turbine size (2.3 MW)	-0.284	0.065	17.61	1	<0.001

Table 4.9: Results from Tukey's multiple comparisons comparing pairs of curtailment treatments

Contrast	Parameter estimate	Standard error	Degrees of freedom	T statistic	P-value
Minimal versus blanket curtailment	-2.698	0.061	55	-44.063	<0.001
Minimal versus EchoSense curtailment	-2.159	0.062	55	-34.722	<0.001
Blanket versus EchoSense curtailment	0.539	0.064	55	8.371	<0.001

4.2. 2021 results

4.2.1. Fatality estimation for 2021

A total of 192 bat carcasses were recovered during carcass surveys, 103 of which were associated with turbines operating under blanket curtailment and 89 of which were associated with turbines operating under EchoSense curtailment (see Table 4.10). The carcasses were primarily eastern red bat (*Lasiurus borealis*) (78), silver-haired bat (*Lasionycteris noctivagans*) (56), hoary bat (*Lasiurus cinereus*) (40) and big brown bat (*Eptesicus fuscus*) (13) in 2021. No federally endangered species were detected during the fatality surveys.

Table 4.10: Carcasses detected at English Farms during standardized carcass searches in 2021.

Species	Blanket curtailment (5 m/s cut-in wind speed) N = 29	EchoSense (5 m/s cut-in wind speed and bat activity) N = 27	Carcasses found at turbines removed from study N = 13	Total N = 69
Eastern red bat (*Lasiurus borealis*)	37	32	9	78
Silver-haired bat (*Lasionycteris noctivagans*)	30	17	9	56
Hoary bat (*Lasiurus cinereus*)	14	20	6	40
Big brown bat (*Eptesicus fuscus*)	7	5	1	13
Tricolored bat (*Perimyotis subflavus*)	1	2	0	3
Evening bat (*Nycticeius humeralis*)	0	1	0	1
Little brown bat (*Myotis lucifugus*)	0	1	0	1
Total*	**89 (3.07)**	**78 (2.89)**	**25 (1.92)**	**192 (2.78)**

**Number in parentheses is average per turbine*

Searcher efficiency was estimated based on data from 58 bat carcasses placed out for detection by searchers: 45 at full plots and 13 at road and pad plots. Two additional carcasses placed for the trials were scavenged prior to the trial taking place. When plot type was included as a candidate covariate, AICc scores from the models fitted indicated that the most parsimonious model was the intercept-only model (ΔAICc = 2.15). However, inclusion of visibility class did improve the model (ΔAICc = 2.52) and was therefore used to calculate the searcher efficiency values taken forward for fatality estimation. Searcher efficiency estimates are presented in Table 4.11.

Table 4.11: Searcher efficiency estimates from GenEst for 2021

Visibility class / plot type	Number of carcasses available for detection	Number of carcasses detected	Estimated searcher efficiency (median and 90% CIs)
Easy	21	18	0.86 (0.68 – 0.94)*
Moderate/difficult	37	22	0.59 (0.46 – 0.72)*
Full plot	45	31	0.69 (0.58 – 0.78)**
Road and pad	13	9	0.69 (0.58 – 0.78)**

**Taken forward for fatality estimation; **Taken forward as a correction factor for assessment of curtailment strategy effect*

Carcass persistence times was estimated based on data from 60 bat carcasses, 46 of which were placed at full plots and the remaining 14, at roads and pads. The lowest AICc score was associated with a Weibull model with no explanatory covariates, however, the difference in AICc values between this and a Weibull model with plot type as an explanatory covariate was small (0.46). Since models with a difference in AIC of less than 2 can be considered to have similar levels of support, and plot type is expected to affect persistence time (with carcasses on roads and pads likely to be more detectable to scavengers than in full plots), this model was taken forwards for the fatality estimation. Carcass persistence estimates are presented in Table 4.12.

Table 4.12: Carcass persistence estimates from GenEst for 2021, modelled using a Weibull distribution with plot type as an explanatory covariate

Plot type	Number of carcasses	Estimated persistence time (median and 90% CIs)	Probability that a carcass is present at the end of the 3-day search interval (r3) (median and 90% CIs)
Full plot	46	2.58 (2.17 – 3.08)	0.74 (0.67 – 0.80)
Road and pad	14	1.96 (1.46 – 2.64)	0.64 (0.52 – 0.75)

Detection probability and DWP for turbines of each plot type is shown in Table 4.13.

Table 4.13: Estimated detection probabilities as provided by GenEst and with incorporation DWP for 2021

Plot type	DWP (Mean and 90% CIs)	GenEst detection probability (median and 5 and 95% quantiles)	Detection probability adjusted for DWP of area (median and 5 and 95% quantiles)
Full plot	0.59 (0.59 – 0.59)	0.51 (0.42 – 0.59)	0.30 (0.25 – 0.35)
Road and pad	0.09 (0.05 – 0.13)	0.44 (0.34 – 0.55)	0.04 (0.02 – 0.07)

The total estimated mortality for the site during the survey period and the estimated mortality per MW and per turbine are presented in Table 4.14.

Table 4.14: Estimated number of bat fatalities that occurred at English Farms during the 2021 study period. This number is also presented per MW and per turbine (calculated as total fatalities divided by the nameplate energy generation of 170 MW and 69 turbines respectively)

	Total fatalities (90% CIs)	Fatalities per MW (90% CIs)	Fatalities per turbine per season (90% CIs)
English Farms	1943.1 (1575.7 – 2524.5)	11.4 (9.3 – 14.9)	28.2 (22.8 – 36.6)

4.2.2. Assessment of curtailment strategy effect on fatality rate

The raw number of carcasses found per turbine, standardized to account for differences in the proportion of time that the turbine was operational during the survey period, the DWP, the probability of a carcass persisting to the next search date and the searcher efficiency, are presented in Figure 4.3

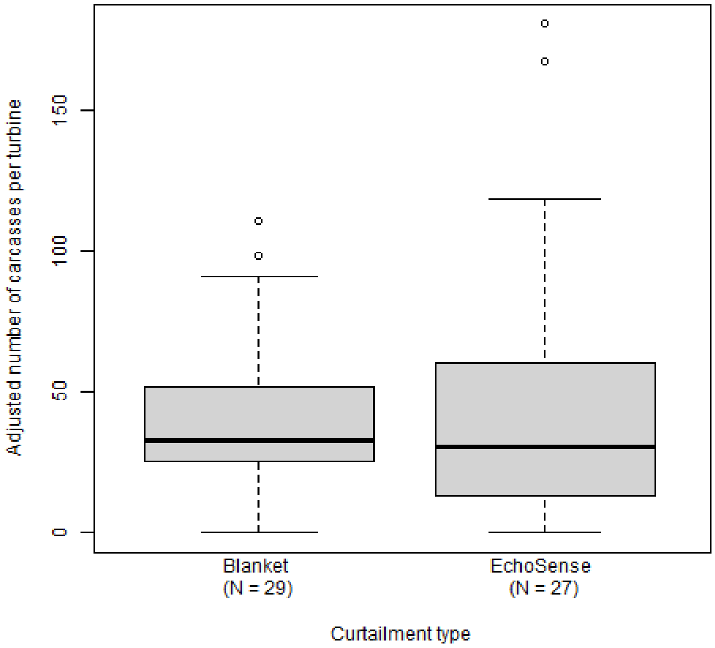


Figure 4.3: Number of bat carcasses detected per turbine in 2021 adjusted for detection probability and turbine operational time. The thick line indicates the median fatality rate, the box represents the interquartile range (IQR; within which 50% of the data are found) and the whiskers represent the quartiles ±1.5 * IQR. Points beyond the whiskers may be considered to be outliers.

A GLM with a Poisson error structure was fit to the data, with turbine size, plot type and treatment included as explanatory factor variables. Model validation indicated that the Poisson error structure was appropriate and that there was no residual spatial autocorrelation among the data points. No statistically significant effects were identified at a threshold of $p < 0.05$ for either turbine size or minimization treatment. However, plot type did predict fatalities with more fatalities predicted at road and pad plots. (This is unlikely to be a biological effect, but rather a residual effect of variation in detection probability among the two plot types). All terms were retained in the final model. Parameter estimates and *p*-values for the model are presented in Table 4.15. With a *p*-value of 0.484, there is no evidence of a difference in the effect of each of the two curtailment systems on bat fatality rate.

Table 4.15: Model parameters and *p*-values from a GLM used to predict the number of carcasses detected per turbine assuming a Poisson error structure

Parameter	Estimate (link scale)	Standard Error	X^2 statistic	Degrees of freedom	*P*-value
Intercept	3.23	0.14	-	-	-
Plot type (Roads and pads)	0.71	0.16	18.63	1	<0.001
Treatment (EchoSense)	-0.11	0.16	0.49	1	0.484
Turbine size (2.3 MW)	0.05	0.19	0.07	1	0.798

4.2.3. Energy yield

EchoSense curtailment was associated with an average 56% reduction in per turbine energy loss when compared to blanket curtailment (5.0 m/s) for the 2021 POR and treatment group. If applied across all 69 turbines at English Farms, EchoSense allowed for 1,684 MWh (3,008 MWh – 1,324MWh) more production compared to blanket curtailment of 5.0 m/s (2021).

To illustrate the differences in control groups, Table 4.18 in Appendix E [Protected] provides the individual turbine results for the POR of the curtailment season (8/1/2021-10/15/2021) and presents the total number of hours each turbine was producing energy, the number of hours unavailable or not producing due to events not related to curtailment, and the number of hours each turbine was curtailed for each treatment group. The energy results presented in Table 4.16 use the nacelle measured wind speed at the time of curtailment and reference power curve discussed in section 3.8 to estimate the lost energy associated with each curtailment event. To calculate the AEP loss, the total production lost due to curtailment was compared against the total potential production for 2020, where total potential production is sum of the reported power and lost energy due to curtailment, on an individual turbine basis and then averaged for each treatment group.

Table 4.16: Per turbine energy yield loss (compared to uncurtailed operation) associated with each 2021 treatment. Numbers in parentheses represent uncertainty (incorporating the standard errors associated with the wind speed analysis and the operational power curve).

Treatment	Number of Turbines	Individual Turbine Average Curtailment Loss (% of AEP*, 90% CIs)	Min Curtailment Loss (% of AEP)	Max Curtailment Loss (% of AEP)	Individual Turbine Average Curtailment Loss (MWh**, 90% CIs)	Predicted Curtailment Loss Across 69 Turbines (MWh**)
Blanket curtailment (5.0 m/s)	29	0.47% (0.44% – 0.50%)	0.2%	0.7%	43.6 (40.3 – 46.9)	3008.3
EchoSense curtailment (5.0 m/s cut-in when bats present)	27	0.21% (0.19 – 0.23%)	0.1%	0.3%	19.2 (17.6 – 20.8)	1324.4

**Annual Energy Production; **Megawatt hours*

4.2.4. Assessment of curtailment strategy effect on energy loss

The predicted curtailment-related energy loss per turbine, standardized to account for differences in the proportion of time that the turbine was operational during the survey period is presented in Figure 4.4.

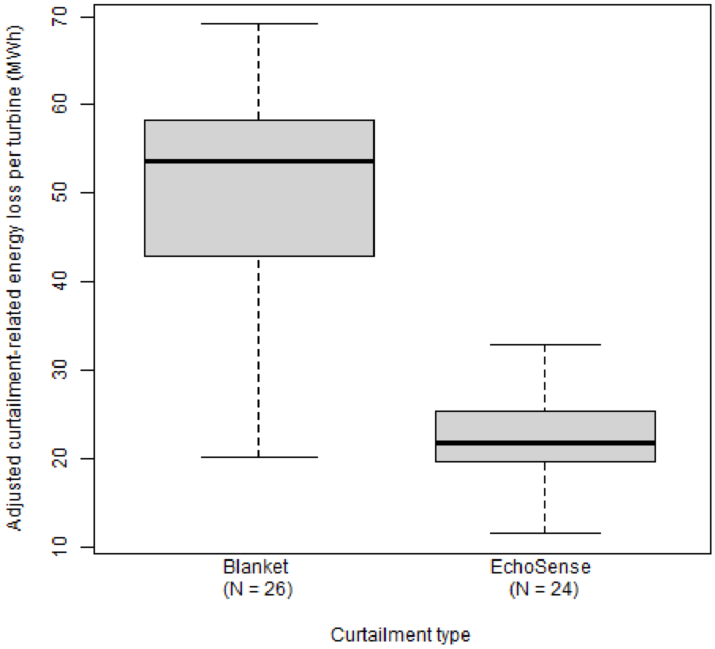


Figure 4.4: Predicted curtailment-related energy loss per turbine in 2021 adjusted for turbine operational time. The thick line indicates the median energy loss, the box represents the interquartile range (IQR; within which 50% of the data are found) and the whiskers represent the quartiles ±1.5 * IQR.

A GLM with a Gamma error structure and a log link was fit to the data, with turbine size and treatment included as explanatory factor variables. Model validation indicated that the error structure was reasonable and that there was no residual spatial autocorrelation among the data points. Both curtailment treatment and turbine size predicted curtailment-related energy loss, with higher losses associated with blanket curtailment compared to EchoSense curtailment and with the larger turbines compared to the smaller turbines. All terms were retained in the final model. Parameter estimates and *p*-values for the model are presented in Table 4.17. There is strong support for an effect of the EchoSense system applied upon the energy loss resulting from curtailment ($p<0.001$).

Table 4.17: Model parameters and *p*-values from a GLM used to predict energy loss per turbine

Parameter	Estimate	Standard Error	X^2 statistic	Degrees of freedom	*P*-value
Intercept	4.012	0.033	-	-	-
Treatment (EchoSense)	-0.880	0.043	393.84	1	<0.001
Turbine size (2.3 MW)	-0.646	0.056	113.98	1	<0.001

5. Discussion

The EchoSense smart curtailment system has been developed by Natural Power with the goal of reducing bat fatalities when compared to the absence of a minimization regime, while simultaneously reducing energy lost due to minimization compared to a blanket curtailment regime, or allowing curtailment at higher wind speeds for similar AEP loss compared to blanket curtailment at lower wind speed cut-ins. In this study, we compared the performance of minimization using the EchoSense system against blanket curtailment at the same cut-in wind speed in terms of numbers of bat fatalities and potential energy yield lost to curtailment.

It is important to note that in both years of the study, operational issues surrounding the turbine controls were encountered and our experimental design was implemented imperfectly. This was due to a mixture of issues including system configurations and communications with IT systems, software, and SCADA. Many of these issues were addressed as they were identified, and further refinement of protocols will be made to prevent these issues on subsequent projects using EchoSense. A key challenge of utilizing wind wildlife technology is the integration of third-party systems into the SCADA network and this was reinforced when trying to implement smart curtailment during these studies. As part of the refinement process increased oversight of the software configuration and documentation are now regularly part of the commissioning process. The system now also includes automated error reporting, system diagnostics, and real-time dashboards with increased staff visibility. Additionally, the controlling software has been broken into independent services with the ability to auto-recover from failures and all software code is closely peer-reviewed and includes live debugging services.

One of the original stated goals for this project was to demonstrate that the EchoSense system results in at least a 50% reduction in fatalities when compared to no minimization. The performance of both the EchoSense system and blanket curtailment were compared to a control in which turbine blades were feathered below 3.0 m/s during the first year of the study (2020). However, despite the assumption that blanket curtailment should reduce fatality rates by at least 28%, there was no statistical support that either treatment differed significantly from the control turbines. This contrasts with numerous studies that have found that blanket curtailment significantly reduces fatality rates. In a meta-analysis of 19 studies conducted across 8 wind energy facilities with the majority in the U.S. (n=7), Whitby et al. (2021) found that total estimated bat fatalities are reduced by 33% for every 1.0 m/s increase in cut-in speed and at a 6.5 m/s cut-in speed, fatalities are reduced by an average of 79% (95% CI: 62-85%) when results are extrapolated across multiple facilities and years. In another meta-analysis of 36 studies conducted across 17 wind energy facilities throughout the U.S. and Canada, Adams et al. (2021) found strong evidence for fatality reduction by blanket curtailment, that is, there was an average of 63% (95% CI: 54-70%) decrease in fatalities across all treatments.

The lack of a difference among treatments, especially in contrast to normal operation, could be explained if few bat collisions occur at wind speeds between 3 m/s and 6.9 m/s. At this site, pre-construction studies suggested that bat activity occurs at higher wind speeds than has been observed at most other wind farm sites, with 72% of activity occurring at wind speeds of above 6.9 m/s in 2013 (Appendix C) [PROTECTED]. Since bats are active at higher wind speeds at English Farms than elsewhere, it might also be that most collisions occur at higher (> 6.9 m/s) wind speeds when all turbines would have been operational. Intuitively, it is easy to imagine that collisions are proportionately more common for the same activity levels at higher wind speeds when flying conditions may be more difficult, but as wind speed covaries with bat activity (Weller and Baldwin, 2012), it is difficult to separate effects of wind speed and bat acoustic activity levels on fatality rates leading to a lack of available evidence to support this hypothesis. However, it is perhaps notable that in 2019 many bat fatalities (more than 1,700) were predicted to have occurred at the English Farms site despite all turbines operating under a blanket 6.9 m/s curtailment regime (Alliant Energy, 2020). Furthermore, the estimated rate of 10.26 bats/MW/year at the English Farms site is greater than the median rate (8.39 bats/MW/year) across the Midwest (AWWI 2020)

Another explanation for the lack of a statistical difference among treatments could be a lack of statistical power. A statistical power analysis, an analysis used to calculate the probability of detecting a true underlying difference among treatments when accounting for study design and noise in the data, was carried out prior to the study. This analysis concluded that there was a 75% probability of being able to detect a difference among the control and the two treatment groups if there was a reduction in fatalities of at least 22% associated with either of the treatments (Appendix B). However, statistical power was reduced by the fact that realized sample sizes were smaller, and the design less balanced than planned due to turbine operational failures. Indeed, a subsequent power analysis carried out for the realized experimental design suggested that the 28% reduction in fatality rate predicted to be associated with the curtailment treatments during suitability analysis for the site would be detected with just a 44% probability (Appendix B).

Increased power can be achieved by increasing sample size, but it can also be achieved by reducing noise (unexplained variation) in the data. Fatality rates predicted in this study were associated with large confidence intervals and this noise can mask underlying patterns in the data. In fatality studies, detection rates can be a large source of noise, with factors such as the effective area surveyed (DWP) and the proportion of carcasses found (determined by searcher efficiency and carcass persistence) playing a key role in the precision of estimates. Several measures could be implemented to reduce this effect including surveying more, and/or larger full plots (reducing uncertainty arising from DWP), conducting carcass searches more regularly (reducing uncertainty associated with carcass persistence) and increasing mowing frequency (maximizing searcher efficiency), as well as increasing the sample sizes used to determine correction factors. In this study, the study design was constrained by practical considerations. However, this has resulted in difficulty distinguishing a lack of effect versus a lack of statistical power.

During the second year of the study (2021), only two treatments were included: blanket curtailment and EchoSense curtailment, both applied at a 5 m/s cut-in wind speed. The reduction in treatments from three to two is associated with an increase in statistical power to detect differences among the treatments, because a greater number of turbines can be enrolled in each treatment. The lack of support for a difference among blanket curtailment and EchoSense curtailment in terms of bat fatality rate in 2021 suggests that at this site, EchoSense curtailment and blanket curtailment result in a similar bat fatality rate.

The second goal of the study was to demonstrate that the EchoSense system results in at least a 50% reduction in energy loss when compared to blanket curtailment at the same wind speed cut-in. The suitability analysis carried out for the site, prior to implementation, suggested that blanket curtailment at a 6.9 m/s cut-in would result in an AEP (Annual Energy Production) loss of between 1.1 and 1.6% while the EchoSense system should result in a loss of around 0.1%. However, in this study, curtailment loss associated with blanket curtailment was 2.1% (6.9m/s cut-in) and 0.5 % (5.0 m/s cut-in) while curtailment loss associated with EchoSense curtailment was 1.2% and 0.2% for the 2020 and 2021 studies, respectively. The difference in pre-construction estimates versus real-world estimates can be attributed in small part, to the fact that the suitability analysis was carried out assuming no curtailment rather than the final control regime (3.0 m/s) used in this study. However, a more significant factor which likely contributed to this discrepancy is wake and hysteresis effects. These calculations were based on a methodology which did not include wake effects on measured wind speeds or hysteresis (the effect of recent events on the status of the system). Not considering wake effects in the suitability analysis curtailment loss estimates means that the estimates were based on a free-stream wind speed, resulting in higher wind speeds in the suitability assessment and therefore less time below cut-in. Additionally, curtailment was observed above the specified cut-in wind speeds by amounts as much as 0.6 m/s. This is due to a combination of hysteresis effects and SCADA control implementation considerations which cannot be quantified in the suitability assessment without assessing real world operations of the curtailment strategies. These are now incorporated as standard in suitability analysis calculations carried out by Natural Power prior to implementation of the EchoSense system.

EchoSense curtailment represented a reduction in energy loss of 41% compared to blanket curtailment at 6.9 m/s (year one) and a 56% reduction compared to blanket curtailment at 5.0 m/s (year two). The reduction in energy loss by approximately 5,490 MWh that would have been achieved by EchoSense curtailment compared to blanket curtailment at a 6.9 m/s cut-in speed is roughly equivalent to having an additional turbine on site, if applied across all 69 turbines. The 1,684 MWh reduction in energy loss that would have been achieved by EchoSense curtailment compared to blanket curtailment at a 5.0 m/s cut-in speed also represents a significant increase in energy production across all turbines. In addition to the reduced energy losses, the variability of losses within the EchoSense curtailment treatment group were notably lower than the blanket curtailment treatment groups, as illustrated by Figure 4.4. The reduced variability lowers the associated energy uncertainty and could therefore reduce the spread of probability of exceedance cases in pre-construction energy estimates. This reduction in uncertainty in conjunction with the almost 1% recovery of per turbine energy loss between the blanket (2.13%) versus EchoSense (1.24%) minimization strategies in the 2020 study and 0.3% energy recovery in the 2021 study is financially meaningful and could make the difference between an economically viable and unviable project.

While Natural Power utilized industry standard operational assessment methodologies to analyze the results of this study and perform the energy analysis, there are methodology improvements that would allow more statistically robust analysis of the turbine's power output. This could be done via non-parametric, multivariate methods that can incorporate many environmental variables as opposed to just wind speed and temperature as was done in this study, such as the kernel plus method (Lee, 2015). Currently, these more robust statistical approaches are not commonplace in the wind energy consultant space, but any future study with similar goals would be improved by incorporating these new statistical methods and comparing the results to more industry standard approaches.

5.1. Conclusion

The goals of this study were to demonstrate at least a 50% decrease in bat fatalities associated with EchoSense turbines as compared to control turbines, and a 50% reduction in energy loss associated with EchoSense turbines as compared to the blanket curtailed turbines. These goals were not met in the first year of the study due to technical issues (41% reduction in 2020), but the EchoSense system did achieve a reduction in energy loss of greater than 50% in the second year of the study (56% in 2021). The EchoSense smart curtailment system was able to considerably reduce lost energy (1,684-5,490 MWh) associated with curtailment for bats compared to a blanket curtailment system and would thereby provide substantial economic benefits over blanket curtailment at the site. The study also found no evidence that the rate of bat fatalities associated with EchoSense turbines differed to that associated with blanket curtailment when applied at the same cut-in wind speed at this site. Further studies will be required to confirm the generality of these findings.

6. References

Adams, E.M., Gulka, J. and K.A. Williams. 2021. A review of the effectiveness of operational curtailment for reducing bat fatalities at terrestrial wind farms in North America. PloS one, 16(11), p.e0256382.

Alameda County Wind Repowering Technical Advisory Committee (ACWRTAC). 2022. Final Bat Fatality Recommendations. Memo to Albert Lopez, Planning Director, Alameda County Community Development Agency. April 28, 2022. 11 pp.

Alliant Energy. 2020. Post-construction small bird and bat mortality survey report. English Farms Wind Energy Facility. Project No. 117095. Version 2.0.

American Wind Wildlife Institute (AWWI). 2020. AWWI Technical Report: 2nd Edition: Summary of Bat Fatality Monitoring Data Contained in AWWIC. Washington, DC.

Arnett, E.B., and E.F. Baerwald. 2013. Impacts of Wind Energy Development on Bats: Implications for Conservation. In R. A. Adams and S. C. Pedersen, editors. Bat Evolution, Ecology, and Conservation. Springer New York: pp. 435–456.

Arnett, E.B., Brown, W.K., Erickson, W.P., Fiedler, J.K., Hamilton, B.L., Henry, T.H., Jain, A., Johnson, G.D., Kerns, J., Koford, R.R., and C.P. Nicholson. 2008. Patterns of bat fatalities at wind energy facilities in North America. The Journal of Wildlife Management, 72(1), pp.61-78.

Arnett, E.B., Huso, M.M., Schirmacher, M.R. and J.P. Hayes. 2011. Altering turbine speed reduces bat mortality at wind-energy facilities. Frontiers in Ecology and the Environment, 9(4), pp.209-214.

Baerwald, E.F., Edworthy, J., Holder, M., and R.M. Barclay. 2009. A large-scale mitigation experiment to reduce bat fatalities at wind energy facilities. The Journal of Wildlife Management, 73(7), pp.1077-1081.

Behr, O., Brinkmann, R., Hochradel, K., Mages, J., Korner-Nievergelt, F., Niermann, I., Reich, M., Simon, R., Weber, N., and M. Nagy. 2017. Mitigating bat mortality with turbine-specific curtailment algorithms: A model based approach. In Wind energy and wildlife interactions (pp. 135-160).

BIPM 2008, Evaluation of measurement data - Guide to expression of uncertainty in measurement, BIPM, 2008, International Bureau of Weights and Measures.

Frick, W.F., Baerwald, E.F., Pollock, J.F., Barclay, R.M.R., Szymanski, J.A., Weller, T.J., Russel, A.L., Loeb, S.C., Medellin, R.A., and L.P. McGuire. 2017. Fatalities at wind turbines may threaten population viability of a migratory bat. Biological Conservation, 209, 172–177.

ECMWF. (2020). Retrieved from ERA5: https://confluence.ecmwf.int/display/CKB/ERA5

61400-12-1, 2017, Wind Energy Generation Systems–- Part 12-1: Power Performance Measurements Of Electricity Producing Wind Turbines, 2017, International Electrotechnical Commission [IEC]

TR-1-2021, ACP, American Clean Power Association (ACP) ACP TR-1-2021 Wind Farm power Performance Technical Report, 2021, American Clean Power Association

Friedenberg, N.A. and W.F. Frick. 2021. Assessing fatality minimization for hoary bats amid continued wind energy development. Biological Conservation, 262, p.109309.

Hayes, M.A., Hooton, L.A., Gilland, K.L., Grandgent, C., Smith, R.L., Lindsay, S.R., Collins, J.D., Schumacher, S.M., Rabie, P.A., Gruver, J.C., and J. Goodrich-Mahoney. 2019. A smart curtailment approach for reducing bat fatalities and curtailment time at wind energy facilities. Ecological Applications, 29(4), p.e01881.

Hein, C., Gruver, J., E. Arnett. 2013. Relating Pre-Construction Bat Activity and Post-Construction Bat Fatality to Predict Risk at Wind Energy Facilities: A Synthesis. Report by Bat Conservation International. Report for National Renewable Energy Laboratory (NREL).

Kerns J., Erickson W.P., E.B. Arnett. 2005. Bat and bird fatality at wind energy facilities in Pennsylvania and West Virginia. In: Relationships between bats and wind turbines in Pennsylvania and West Virginia: an assessment of fatality search protocols, patterns of fatality, and behavioral interactions with wind turbines Edited by E.B. Arnett. The Bats and Wind Energy Cooperative, Bat Conservation International, Austin, Texas, pp 24–95.

Korner-Nievergelt, F., Brinkmann, R., Niermann, I. and O. Behr. 2013. Estimating bat and bird mortality occurring at wind energy turbines from covariates and carcass searches using mixture models. PloS one, 8(7), p.e67997.

Lee, G., Ding, Y., Xie, L., and Genton, M. G, 2015. A kernel plus method for quantifying wind turbine performance upgrades. Wind Energ. pp. 1207-1219.

Martin, J. E., Politano , M.S., Prakash, S., Carrica, P.M., and C.D. Markfort. 2017. Optimizing Bat Carcass Search Areas using a CFD-Lagrangian Modeling Approach. Report to MidAmerican Energy Company. Limited Distribution Report No. 414.

Peterson, T.S., McGill, B., Hein, C.D. and Rusk, A., 2021. Acoustic Exposure to Turbine Operation Quantifies Risk to Bats at Commercial Wind Energy Facilities. Wildlife Society Bulletin 45(4), pp.552–565.

R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Roemer, C., Disca, T., Coulon, A. and Y. Bas. 2017. Bat flight height monitored from wind masts predicts mortality risk at wind farms. Biological conservation, 215, pp.116-122.

Schuster, E., Bulling, L., and J. Köppel. 2015. Consolidating the state of knowledge: a synoptical review of wind energy’s wildlife effects. Environmental management, 56(2), pp.300-331.

Simonis, J., Dalthorp, D., Huso, M., Mintz, J., Madsen, L., Rabie, P., and J. Studyvin. 2018. GenEst user guide—Software for a generalized estimator of mortality: U.S. Geological Survey Techniques and Methods, book 7, chap. C19 https://doi.org/10.3133/tm7C19.

Smallwood, K.S., 2020. USA wind energy-caused bat fatalities increase with shorter fatality search intervals. Diversity, 12(3), p.98.

Smallwood, K.S. and D.A. Bell. 2020. Relating bat passage rates to wind turbine fatalities. Diversity, 12(2), p.84.

Solick, D., Pham, D., Nasman, K. and Bay, K., 2020. Bat activity rates do not predict bat fatality rates at wind energy facilities. Acta Chiropterologica, 22(1), pp.135-146.

U.S. Fish and Wildlife Service (USFWS). 2020. Requirements for issuing a Technical Assistance Letter for avoidance of Indiana and northern long-eared bat take at wind energy facilities in Indiana. Revised. 6/12/2020. https://www.fws.gov/sites/default/files/documents/TAL%20Requirements_INFO061220.pdf

Weller, T.J., and J.A. Baldwin. 2012. Using echolocation monitoring to model bat occupancy and inform mitigations at wind energy facilities. The Journal of Wildlife Management, 76(3), pp.619-631.

Whitby, M.D., M.R. Schirmacher, and W.F. Frick. 2021. The state of the science on operational minimization to reduce bat fatality at wind energy facilities. A report submitted to the National Renewable Energy Laboratory. Bat Conservation International. Austin, Texas.

Zimmerling J.R. and C.M. Francis. 2016. Bat mortality due to wind turbines in Canada. The Journal of Wildlife Management. 80(8), pp.1360-9.

Appendices

A. Cost Analysis - PROTECTED

B. Statistical Power Analysis – UNLIMITED

1. Introduction

A study was carried out at the English Farms Wind Farm to test the efficacy of the EchoSense bat smart curtailment system compared to a control and a blanket curtailment regime. A power analysis carried out before the study predicted that a 22% reduction in bat fatality rate associated with the two curtailment treatments compared to the control treatment would be detected with 75% probability. A 28% reduction in bat fatality rate was predicted based on a pre-study suitability analysis. However, due to operational failures on site, the final sample sizes were reduced, and the design was less balanced than the planned design. These factors will have reduced the power of the design. Here we present a subsequent power analysis assessing the power of the final design.

2. Methods

The power analysis was carried out within the R statistical programming environment (R Core Team, 2018) using the powersim function in the simr package (Green and MacLeod, 2016[1]). This function uses a model fitted from an existing or simulated dataset with known effect size for the parameter(s) of interest to repeatedly generate new values for the response variable, refit the model and apply a statistical test to the simulated fit. The power is calculated based on the proportion of times that a significant effect of the parameter of interest is detected. The power analysis was run using a generalized linear model ("GLM") input with a Poisson error structure fitted from a dataset incorporating the properties of the 2020 English Farms dataset (turbine-specific Density Weighed Proportion ("DWP") and turbine size, influence of plot type and turbine size and residual error structure), and a range of effect sizes for the treatment parameter. The GLM modelled the number of carcasses detected as a response to plot type, turbine size and treatment and incorporated an offset variable calculated based on the DWP, searcher efficiency and carcass persistence rates taken from the 2020 dataset. Each power estimate is based on 1000 simulations and the significance level for the statistical test was set to 0.05.

3. Results

The supplementary power analysis suggested that a reduction of fatalities of roughly 37% would have been required to detect a significant difference with 75% probability. The reduction in fatality rate of 28%, predicted from the up-front study, would be detected with a 47.3% probability.

---

[1] [1] Green, P. and MacLeod, C.J. (2016), SIMR: an R package for power analysis of generalized linear mixed models by simulation. Methods Ecol Evol, 7: 493-498. https://doi.org/10.1111/2041-210X.12504

C. Task 3 Research Plan 2020 Final – PROTECTED

D. Task 3 Research Plan 2021 Final – PROTECTED

E. Turbine Availability – PROTECTED