Ground-Based Coastal Air Surveillance
Wind Turbine–Radar Interference Vulnerability Study

Public Summary

12/8/17

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Acknowledgments

This summary is based on research done by Jason Biddle and Lorri Parker of MIT Lincoln Laboratory, supported by the Department of Energy. A number of other people were also essential to the development of this report, including the entire Wind Turbine Radar Interference Working Group, particularly Senior Steering Group members Jim Baird of the Federal Aviation Administration, Jud Stailey of the National Oceanic and Atmospheric Administration, Steve Sample of the Department of Defense, and Patrick Gilman of the Department of Energy. For their additional review of the document, we thank Joe Anello of the Department of Homeland Security, and Jen Miller of the Bureau of Ocean Energy Management.

PUBLIC SUMMARY

Offshore wind represents a significant opportunity to the United States, as highlighted by the U.S. Department of Energy (DOE) and the U.S. Department of the Interior (DOI) in a joint national offshore wind strategy published in 2016 [1]. U.S. offshore wind resources are abundant and accessible using existing technology, and a robust offshore wind industry would lead to significant positive environmental and economic external benefits according to the strategy. However, key challenges remain to support a robust offshore wind industry, including effective stewardship of ocean and Great Lakes resources. Offshore wind facilities may impact competing uses such as air traffic control, air surveillance, weather, and navigational radar systems, and the strategy notes further study is needed.

The effects of land-based wind turbines on radar systems are well understood. Wind turbines within radar line-of-sight can increase clutter that may inhibit target detection, increase the generation of false targets, interfere with target tracking, and hinder weather forecasting [2]. However, the effects of offshore wind turbines on U.S. coastal radar systems are not well understood due to the lack of operational wind facilities for empirical study. Offshore wind turbines may pose unique impacts to coastal radar systems given the differences in propagation of radar signals over the ocean versus land, as well as the larger size of offshore wind turbines compared to land-based wind turbines.

Determining risk and assessing wind turbine interference impacts on a given radar system is a complex question. It requires analysis based on the training or operational missions supported by the radar system, the targets that must be detected, and the broader radar clutter environment. MIT Lincoln Laboratory (MIT LL) has previously performed such studies for specific homeland defense missions and specific radar systems. This study is mission agnostic and does not constitute a full assessment of offshore wind turbine interference impacts or mitigation. It should viewed as the first of many steps in determining where there is potential for impacts in terms of geographic areas and radar types.

In this study, MIT LL evaluated the potential impacts to first order of existing and currently planned offshore wind facilities on ground-based coastal air surveillance radar. Mitigation measures, including radar network fusion, radar upgrades, and infill systems, are also discussed. The analysis for existing facilities focused on Block Island Wind Farm, the first commercial offshore wind farm in the U.S. The analysis for future facilities focused on the Bureau of Ocean Energy Management (BOEM) renewable energy lease areas and wind planning areas.

Block Island Wind Farm (BIWF) is the first and only commercial offshore wind facility in the U.S. as of 2017. BIWF is comprised of five 6-megawatt (MW) offshore wind turbines located three nautical miles southeast of Block Island, RI. BIWF became operational in December 2016. Three coastal radar systems surveil the airspace above BIWF, two long range air-surveillance radars and one airport terminal radar.

The terminal radar can detect the BIWF wind turbines, as well as targets flying above them, based on radar line-of-sight (LOS) predictions. The BIWF wind turbines are below the coverage of the two long-range air surveillance radars and thus should not be detectable based on LOS predictions. MIT LL analyzed primary radar output data from 2015 and from September 2016 through March 2017, before and after BIWF became operational. The terminal radar consistently detects BIWF as predicted by LOS. Compared to the baseline false alarm rate in the area around Block Island, the wind turbines increase the false alarm rate by approximately two orders of magnitude. The elevated terminal radar false alarm rate around BIWF does not impact flight operations according to feedback from local FAA air traffic controllers, as BIWF is not located along an airport approach, and the five offshore BIWF turbines occupy a small spatial area.

The study found that the long-range air surveillance radars do not typically detect BIWF, which is consistent with LOS predictions however, the analysis did identify brief periods of detection. Detections by coastal radar systems outside predicted LOS may be the result of anomalous propagation, where atmospheric conditions result in signal propagation beyond the typical radar horizon. Specifically, super refraction and atmospheric ducting can cause anomalous propagation in coastal environments. Analysis of data from nearby surface weather stations did not produce any obvious patterns or anomalies during these periods. MIT LL recommends additional study in this area using radiosonde upper-air observation data to better understand and incorporate the frequency of these conditions into wind turbine–radar interference models for coastal environments.

The analysis for future wind facilities focused on the BOEM renewable energy lease areas and wind planning areas [3]. BOEM manages 14 lease areas along the U.S. east coast and 11 planning areas along the east coast, west coast, and Hawaii, which are shown in Figure 1. Commercial wind development is more likely to occur in the lease areas before the planning areas.

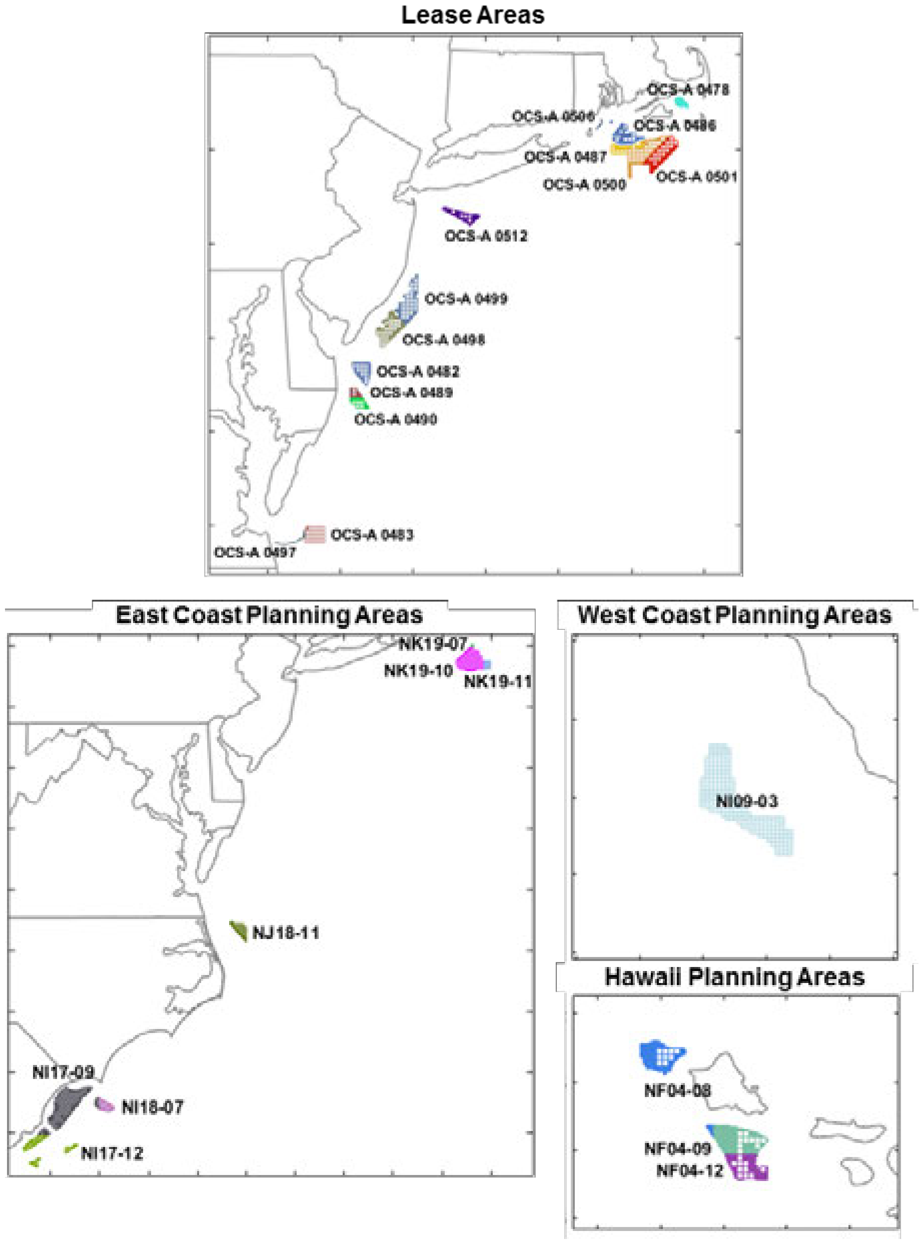

Figure 1. BOEM renewable energy lease areas and wind planning areas.

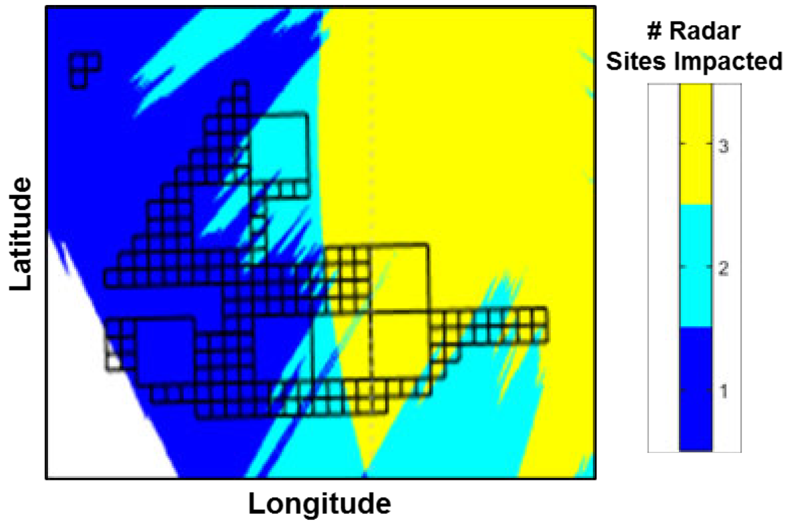

Figure 2. Map of OCS-A 0486 showing how many radar sites could be impacted by future offshore wind facilities deployed in different regions of the lease.

For both sets of areas, MIT LL performed LOS predictions for coastal air surveillance radar with offshore wind turbine size assumptions from a 2016 expert elicitation survey by Lawrence Berkeley National Laboratory (LBNL) [4]. LBNL forecasts that offshore wind turbines with an 11-MW generation capacity, 190 meter rotor diameter, and 220 meter total height could be viable by 2030. The study considered coastal air surveillance radar (i.e., CARSR and ARSR-4 types) and terminal air traffic control radar (i.e., ASR-8, ASR-9, and DASR/ASR-11 types), which are subsequently referred to as LRR for long-range radar systems and SRR for short-range radar systems. Figure 2 shows an example of the LOS output.

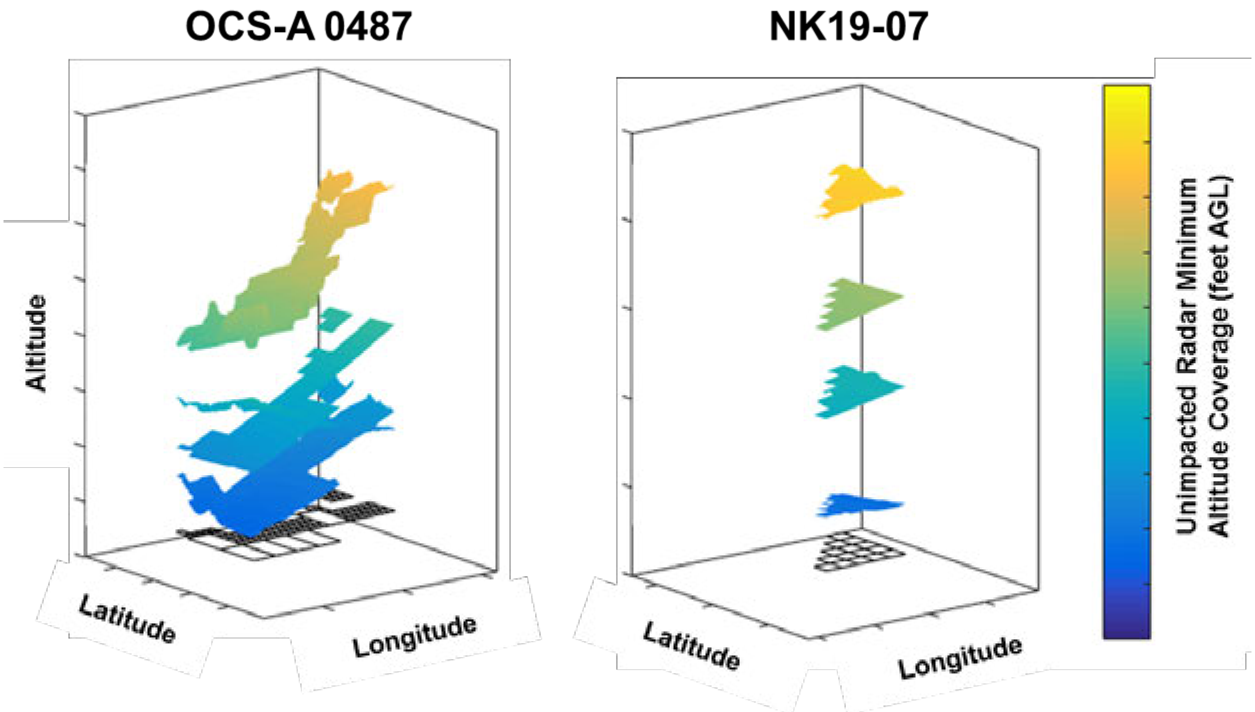

Figure 3. Example of overlapping coverage from multiple unimpacted radar systems above an offshore lease area (left) and a planning area (right).

For lease or planning areas where an impact is predicted, one mitigation approach would be to fuse output from a nearby unimpacted LRR or SRR that surveils the airspace above the offshore wind turbines but cannot see low enough to detect the wind turbines. MIT LL also analyzed overlapping coverage of the lease and planning areas from unimpacted SRR and LRR. For many of the lease and planning areas, fusion of output from these radar systems can restore some mid- and high-altitude detection performance as illustrated in Figure 3. However there are some lease and planning areas, particularly those along the coasts of Hawaii, as well as Massachusetts and Rhode Island, where unimpacted overlapping coverage does not exist and different mitigations would be needed. It is also important to note this fusion mitigation approach cannot restore low altitude coverage from 500-1000 feet AGL.

Mitigations for land-based wind turbine impacts to air surveillance radar are currently in various stages of development, testing, and deployment. These mitigations include existing radar upgrades and infill radar systems. The radar upgrades developed to date have primarily focused on the CARSR LRR and the DASR/ASR-11 SRR. However, the ARSR-4 LRR and ASR-9 SRR are the most impacted types by future offshore wind deployment based on this analysis. Additional study is needed to determine the transferability and performance of CARSR and DASR/ASR-11 upgrades given significant architectural differences between these types and the ARSR-4 and ASR-9. Low cost upgrades may be challenging given legacy hardware and processing constraints.

Infill radar systems showed promise in mitigating land-based wind turbines during the Interagency Field Test and Evaluation (IFT&E) program [2]. Further testing and integration of infill radar systems is ongoing at locations such as Travis Air Force Base in California and near Oilton, Texas. Siting may be a key challenge in using some infill radar systems to mitigate offshore wind turbines. Shorter-range infill systems may need to be co-located with the offshore wind facility to leverage power and communications infrastructure, which may limit their coverage above the wind turbines due to cone of silence effects. Many infill radar systems tested during the IFT&E program also exhibited high false alarm rates from ground clutter well beyond wind farms, and sea clutter may be even more challenging.

REFERENCES

1. U.S. Department of Energy (DOE) and U.S. Department of the Interior (DOI). 2016. *National Offshore Wind Strategy: Facilitating the Development of the Offshore Wind Industry in the United States*. DOE/GO-102016-4866. Washington, D.C. (US). https://energy.gov/sites/prod/files/2016/09/f33/National-Offshore-Wind-Strategy-report-09082016.pdf

2. Karlson, B., et al. 2014. *Interagency Field Test and Evaluation (IFT&E) Industry Report: Wind Turbine–Radar Interference Test Summary.* SAND2014-19003. Albuquerque, NM (US). https://energy.gov/sites/prod/files/2014/10/f18/IFTE%20Industry%20Report_FINAL.pdf

3. U.S. Department of the Interior (DOI) Bureau of Ocean Energy Management (BOEM). 2017. *BOEM Renewable Energy Program Fact Sheet*. https://www.boem.gov/BOEM-RE-Programs-Fact-Sheet/

4. Wiser, R.H., et al. 2016. *Forecasting Wind Energy Costs and Cost Drivers: The Views of the World's Leading Experts*. LBNL-1005717. Berkeley, CA (US). https://eetd.lbl.gov/sites/all/files/ lbnl-1005717.pdf