APPENDIX A

Scoping Report

Environmental Impact Statement Scoping Report for the Campo Wind Project with Boulder Brush Facilities

Prepared for:

Bureau of Indian Affairs
Pacific Regional Office
2800 Cottage Way
Sacramento, California 95825

Prepared by:

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Encinitas, California 92024

MAY 2019

Printed on 30% post-consumer recycled material.

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APPENDICES

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1 INTRODUCTION

The Bureau of Indian Affairs (BIA), as lead agency, intends to prepare an Environmental Impact Statement (EIS) regarding the approval of a lease between the Campo Band of Diegueño Mission Indians (Tribe) and Terra-Gen Development Company LLC (Terra-Gen; developer), to construct and operate a renewable energy generation project for 25 years on the Campo Indian Reservation (Reservation). The proposed action would authorize a lease that would allow Terra-Gen to develop and operate a renewable energy generation facility in the lease area, which is referred to throughout this document as "the Project." The Project would generate electricity by wind, a renewable resource, by up to 60 wind turbines.

This scoping report describes the EIS scoping process, identifies the cooperating agencies, explains the purpose and need for the proposed action, describes the proposed Project and summarizes the issues identified during the scoping process.

1.1 EIS Scoping Process

The "scope" of an EIS is the range of environmental issues to be addressed and the types of project effects to be considered. The EIS scoping process is designed to provide an opportunity for the public and other federal and state agencies to help determine the scope of the EIS.

The first formal step in the preparation of an EIS is publication of a Notice of Intent (NOI) to prepare and EIS. The BIA published the NOI for this proposed action in the Federal Register on November 21, 2018 (Appendix A). The NOI describes the proposed action and the reasons why an EIS is being prepared. A public notice announcing the proposed action and the scoping meeting was published in the San Diego Business Journal on November 26, 2018 and the San Diego Union-Tribune on November 21, 2018 (Appendix B). The range of issues typically addressed in an EIS will be modified based on comments received from the public during the scoping process. A list of comment letters received is included as Appendix C. The Preliminary Project Information Package and Comment Letters received during the scoping process are included as Appendix D. A transcript of the public scoping meeting can be found as Appendix E.

1.2 Cooperating Agencies

As lead agency, the BIA may request that other agencies having jurisdiction by law or having special expertise with respect to anticipated environmental issues be "cooperating agencies." Cooperating agencies participate in the scoping process and, on the lead agency's request, may develop information to be included in the EIS. The BIA will meet with cooperating agencies periodically and keep them informed of the status of the National Environmental Policy Act (NEPA) process.

The BIA has formally invited the Tribe's Campo Environmental Protection Agency (CEPA) and the County of San Diego (County) to participate in the EIS as cooperating agencies.

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2 PROPOSED ACTION

The Project would include the construction and operation of up to 60 wind turbines for generation of up to 252 megawatts (MW). The Project study area covers approximately 2,200 acres on the Campo Reservation and approximately 500 acres on private lands within the County. The total area that would be disturbed by the Project would be substantially less. The wind power generation facility would operate year-round for a minimum of 25 years. Additional details regarding the Project components and construction can be found in Appendix B, Project Details, to this Draft EIS.

2.1 Purpose and Need

The purpose and need for the BIA's proposed action is to consider the Tribe's request for a lease of trust land consistent with its role overseeing trust lands and with federal leasing law/regulations. A secondary purpose in considering approval of the Tribe's proposed lease is to increase national and tribal renewable energy sources to increase federal energy independence and decrease greenhouse gas emissions as encouraged by state and federal law.

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3 ISSUES IDENTIFIED DURING SCOPING

3.1 Introduction

The Council on Environmental Quality regulations for implementing NEPA require a process, referred to as "scoping," for determining the range of issues to be addressed during the environmental review of a Proposed Action (25 CFR 1501.7). The scoping process entails a determination of issues by soliciting comments from agencies, organizations, and individuals. The NOI comment period for the Proposed Project's EIS began November 21, 2018, and closed on December 21, 2018. The issues that were raised during the NOI comment period have been summarized in this Scoping Report.

The following section lists each of the major issue areas raised by members of the public or government agencies in the scoping process. Specific issues and questions are discussed in each section and will be further addressed in the EIS. Additional issues not specifically raised but which the BIA intends to address in the EIS also are discussed. A list of comments received is provided in Appendix C, and copies of the comment letters submitted during the scoping process appear in Appendix D. A transcript of the public scoping meeting held at the Campo Indian Reservation Tribal Hall, 36190 Church Road, Campo, California on December 6, 2018, is provided in Appendix E.

3.2 Issues Identified During Scoping

This section contains a summary of comments received during the EIS scoping process. These comment summaries are categorized by issue area. A general summary of the expected scope of the EIS for each issue area category is also provided.

3.2.1 Air Quality and Greenhouse Gas Emissions

Comments

The following comments and questions regarding the air quality were provided during scoping:

- Discuss changes in air quality resulting from fires and increased fugitive dust.
- Discuss ambient air conditions, National Ambient Air Quality Standards, criteria pollutant nonattainment areas, and potential air quality impacts of the proposed Project (including cumulative and indirect impacts).
- Address applicability of Clean Air Act Section 176 and the U.S. Environmental Protection Agency's general conformity regulations at 40 CFR, Parts 51 and 93.

- Identify the location of sensitive receptors in the Project area, and locate construction equipment and staging zones away from those receptors.
- Implement fugitive dust controls such as phasing grading operations where appropriate, installing wind erosion control techniques, etc.
- Discuss greenhouse gas emissions from Project construction and operation and the Project's lifecycle emissions, including those associated with manufacturing and transporting of the wind turbines, towers, and power lines.
- Discuss the impacts to local climate and moisture retention.

EIS Scope

The EIS and appended technical studies will include a full description of the regional climate, existing air quality, and pollutants of concern in the vicinity of the Project site. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.2 Water, Wastewater and Drainage

Comments

The following comments and questions regarding water resources were provided during scoping:

- Identify impacts to groundwater and wells during construction.
- Discuss the increasingly limited and unreliable water supply in the Project area.
- Discuss the risk of groundwater supply strain and the proximity to the Campo/Cottonwood Creek Sole Source Aquifer.
- Identify the quantity of water the Project will require, the source of the water, and potential effects of this water use on other water users and natural resources in the Project's impact footprint.
- Describe all waters of the United States that could be affected by the Project.
- Describe the natural drainage patterns in the Project area and identify whether any components of the proposed Project are within the 100-year floodplain.
- Avoid and minimize direct and indirect impacts to drainages, including erosion, migration of channels, and local scour.
- Document the Project's consistency with applicable stormwater permitting requirements including a stormwater pollution prevention plan (SWPPP) and discuss best management practice (BMP) implementation

EIS Scope

The EIS and appended technical studies will include a full description of watersheds, drainage patterns, floodplains, groundwater conditions, and water quality, as well as analysis of potential impacts resulting from the proposed Project on these resources. The EIS will address issues related to stormwater runoff, water consumption, and wastewater generation, including impacts to surface water and groundwater quality. Mitigation measures to avoid or reduce impacts to water quality and water resources, if warranted, will be discussed in the EIS.

3.2.3 Biological Resources

Comments

The following comments and questions regarding biological resources were provided during scoping:

- Discuss habitat degradation resulting from construction and operation of new turbines and associated structures.
- Discuss the removal of mature oak trees along Project access routes to accommodate turbine transport.
- Large turbines could be a deterrent for wildlife native to the area and result in displacement of wildlife to residential areas.
- Discuss impacts to bird populations, specifically golden eagles, as well as landscape-scale avoidance impacts to open-habitat birds. Include expected bird mortality rates.
- Discuss impacts to migratory bird species.
- Discuss impacts to bat populations resulting from collisions and barotrauma.
- Discuss impacts to the wide range of general plant and animal species as well as sensitive species, while addressing ecosystem-level impacts. Include bat mortality rates.
- Address the potential of new access roads to introduce invasive species into new areas, and describe for the Project which meet the requirements of Executive Order 13112.
- Discuss impacts to native vegetation communities.

EIS Scope

The EIS and appended technical studies will include a full description of the habitat and plants and wildlife (including federal and state listed threatened/endangered species) on the Project site, as well as the assessment of reasonably foreseeable impacts of the Project on these resources. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.4 Geology and Soils

Comments

The following comments and questions regarding geology and soil resources were provided during scoping:

- How much grading and filling would be required for Project construction?

EIS Scope

The EIS and appended studies will include a full description of the geological, topographic, site drainage, and soil conditions on the Project site, as well as an analysis of potential impacts resulting from the Project on these resources. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.5 Noise

Comments

The following comments and questions regarding noise were provided during scoping:

- Sixty new turbines will increase noise disturbance and annoyance to sensitive noise land uses such as residential areas.
- Discuss the Project's audible, low-frequency, and infrasound noise impacts, including unweighted noise measurements and estimates as well as the A- and C-weighted estimates.
- Bigger turbines generate more low-frequency noise and vibrations that will travel farther than the existing Kumeyaay Wind and Tule Wind turbines.
- Increased concern for individuals with adverse sensitivities to wind turbine noise.
- Discuss the health impacts of wind-turbine-generated noise, including stress, sleep disturbance, and reduced quality of life.
- Identify the significance threshold used in the impact assessment methodology.
- Include noise estimates for schools that could be impacted by the Project and discuss potential effects of noise on school learning and academic achievement of children.
- Noise from the Kumeyaay Wind and Ocotillo Wind can already be detected at local residences, and the addition of Campo turbines will only exacerbate the already elevated noise levels (cumulative noise).

- Identify construction schedule and expected noise impacts during construction activities.
- Discuss noise impacts on local wildlife populations.

EIS Scope

The EIS and appended technical studies will include a full description of ambient noise surrounding the Project site. The EIS will provide an analysis of any reasonably foreseeable impacts to sensitive noise receptors in the vicinity of the Project from construction and operation. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.6 Traffic and Transportation

Comments

The following comments and questions regarding traffic and transportation were provided during scoping:

- Increased traffic and road damage will result from construction and operation of the new turbines.

EIS Scope

The EIS and appended technical studies will include a full description of the local traffic conditions, including an analysis of existing study area roadways and intersections with the potential to be significantly impacted by Project traffic. The EIS will additionally provide an estimate of the total daily trips and peak hour trips generated by the Project, and include an analysis of any reasonably foreseeable impacts to study area roadways and intersections. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.7 Hazards and Hazardous Materials

Comments

The following comments and questions regarding hazards and hazardous materials were provided during scoping:

- Increased risk of fires and wildfires has been observed with increasing wind energy projects.
- Discuss magnetic field non-ionizing radiation and carcinogenic risk to humans and wildlife.

EIS Scope

The EIS and appended technical studies will include a description of the potential public health and safety conditions at the Project site. The EIS will disclose incidences of past and current hazardous materials incidents and involvements, if any. Additionally, the EIS will address the potential for impacts associated with public health and safety, including the use of hazardous materials during construction and operation of the Project and wildfire risks from implementation of the Project. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.8 Cultural and Historic Resources

Comments

The following comments and questions regarding cultural and historic resources were provided during scoping:

- Potential impacts to historic and cultural sites and resources must be analyzed.

EIS Scope

The EIS and appended technical studies will include a cultural resources analysis that identifies historical and archaeological resources, if any, located within the Project site. Any reasonably foreseeable impacts to historical and archaeological resources will be analyzed in the EIS. The EIS process will include a cultural records search and consultation with the State Historic Preservation Office, Native American Heritage Commission, and consultation under Section 106 of the National Historic Preservation Act. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.9 Land Use Planning and Development

Comments

The following comments and questions regarding land use and planning were provided during scoping:

- Turbines would be too close to homes, and within the impact zone of several miles.

EIS Scope

The EIS will identify existing public policies, including zoning and land use regulations currently applicable to the Project site. Agricultural lands on and in the vicinity of the Project site will be identified and potential Project-related impacts will be analyzed. The potential for land use conflicts to be caused by the Project will also be included within the EIS analysis. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.10 Visual Impacts and Aesthetics

Comments

The following comments and questions regarding visual resources and aesthetics were provided during scoping:

- The wind turbines will dominate and degrade mostly natural landscapes.
- Increased light pollution will adversely impact star-gazing and other night sky-related benefits.
- Larger and taller turbines will have greater adverse visual impacts.
- Constant red lights flashing visible from residential areas is a nuisance to residents.
- Discuss the visual impacts that the Project would have on local scenery, aesthetic enjoyment, and human health, including shadow flicker.

EIS Scope

The EIS and appended technical studies will include a description of the Project site and surrounding land uses and visual qualities. The EIS will provide an analysis of any reasonably foreseeable impacts to visual resources and aesthetics within the study area. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.11 Socioeconomics and Environmental Justice

Comments

The following comments and questions regarding socioeconomics and Environmental Justice were provided during scoping:

- Discuss impacts such as loss of property values and personal investments, as well as increased insurance costs, to properties close to the Project site.
- Adverse impacts to the Golden Acorn Casino area resulting from the Project.
- Identify if there would be disproportionate adverse impacts related to numerous wind turbine projects located in a predominantly low-income and minority area, including Kumeyaay Wind, Tule Wind, Energia Sierra Juarez Wind, and Terra-Gen’s proposed 30-turbine Torrey Wind Project.

- Discuss impacts to environmental justice communities.
- Discuss economic benefits to the Tribe resulting from the Project.

EIS Scope

The EIS will include a description of the socioeconomic conditions of the Reservation and surrounding communities. The EIS will analyze reasonably foreseeable and disproportionate impacts of the Project on minority and low income populations, and analyze socioeconomic issues such as employment, housing, and public services Mitigation measures, if warranted, will be discussed in the EIS.

3.2.12 Emergency Services

Comments

The following comments and questions regarding emergency services were provided during scoping:

- What entity would provide firefighting services to the Project?
- There would be an increased risk to firefighters as wildfires increase in frequency and intensity.

EIS Scope

The EIS will include a description of the fire hazards and fire protection on the reservation. The EIS will provide an analysis of any reasonably foreseeable impacts to emergency services and wildfire risks within the Project area. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.13 Community Character, Rural Values and Quality of Life

Comments

The following comments and questions regarding community character, rural values, and quality of life were provided during scoping:

- There is not enough room for appropriate setbacks to protect public health and safety.
- Electromagnetic interference including cell service and electrical pollution should be analyzed.
- There will be adverse impacts to livestock health.
- Homes near turbines are often abandoned or purchased in response to lawsuits filed against the turbine owners and operators.

- Discuss the potential health and safety impact of *Coccidioides immitis* spores (valley fever) and identify measures to prevent or reduce the risk of exposure to workers and residents.
- The presence of more and larger turbines will diminish the natural landscape and feeling of closeness to nature.
- Discuss impacts to nearby pastures and livestock animals.

EIS Scope

The EIS will include a description of the Project site and surrounding land uses and community character. The EIS will provide an analysis of any reasonably foreseeable impacts to community character, rural values and quality of life, and public health and safety within the study area. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.14 Tribal Issues

Comments

The following comments and questions regarding tribal issues were provided during scoping:

- The Project proponents should recognize the harms of colonization and general attitude of Campo members towards development by external entities.
- By leasing its land, the Campo Tribe will not gain any profits from the Project.
- Consider Tribal opposition to the Project; review the legitimacy of the Campo's General Council vote taken in April 2018.
- Tribal leadership has not adequately engaged with and informed the General Council.

EIS Scope

The EIS will address the social impacts of the Proposed Project on minority and/or low-income Tribal communities. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.15 Cumulative Impacts

Comments

The following comments and questions regarding cumulative impacts were provided during scoping:

- Discuss the cumulative impacts of any connected projects.

- Identify how resources, ecosystems, and human communities of concern have already been affected by past or present activities in the Project area.

EIS Scope

The EIS and appended technical studies will address the cumulative impacts of the Proposed Project and alternatives in connection with reasonably foreseeable actions and projects. "Cumulative impacts" refer to the effects of two or more projects that, when combined, are considerable or compound other environmental effects. The EIS will discuss cumulative impacts and identify appropriate mitigation measures, as required by NEPA. Mitigation measures, if warranted, will be discussed in the EIS.

3.2.16 Mitigation Measures

Comments

The following comments and questions regarding mitigation measures were provided during scoping:

- Vegetation management could be proposed as a mitigation measure to decrease the likelihood of devastating fires in the area.
- Ensure that the Project site is far enough away from homes and businesses so that the noise impacts are reduced.
- Engage with Tribe members to ensure that the Project is not harmful and provides opportunities for the Tribe to directly benefit; provide ownership to the Campo Kumeyaay Nation.
- Discuss the full range of Project impacts and measures to mitigate them.
- Make information on mitigation and monitoring available to the public.

EIS Scope

The EIS and appended technical studies will address public health and safety, including wildfire risks, noise effects, and socioeconomics; if warranted, appropriate mitigation measures according to each resource chapter will be discussed in the EIS.

3.2.17 Procedural and Other EIS Issues

Comments

The following comments and questions regarding procedure and the EIS were provided during scoping:

- BIA should provide more project information and extend the public scoping comment period. The NOI fails to provide enough detail to adequately inform the public about the Project, for example: neither the NOI nor the Project website provides a map showing specific locations of the wind turbines, on-site collector substation, and switchyard. The single map shown via PowerPoint was vague and difficult to interpret.
- NEPA and the California Environmental Quality Act (CEQA) require thorough environmental review of the Project.
- The EIS must provide a full and accurate Project description.
- The EIS must demonstrate a need for the Project. The NOI does not mention the Project purpose or demonstrate a need for the Project. Discuss the need for new industrial-scale energy generation projects and efficiency of industrial-scale wind energy projects.
- Discuss and analyze a full range of Project alternatives.
- The smaller 2.5 MW turbines mentioned in the scope would be more than sufficient to produce 150 MW. Discuss why the scope includes this smaller turbine option if the goal is to generate 252 MW. The 4.2 MW turbines necessary to produce 252 MW would be too large for the proposed region.
- Maintain compliance with California Public Utilities Commission General Order 131-D.

EIS Scope

The EIS will be prepared in accordance with applicable requirements, including those set out in NEPA (42 USC 4321 et seq.); the Council on Environmental Quality Regulations for Implementing NEPA (40 CFR 1500–1508); and the BIA's NEPA Guidebook (59 IAM 3-H) dated August 2012. These issues will be discussed to the extent required under the NEPA process. While generally these are legal and policy issues, sufficient information will be provided to allow public understanding of the background, issues, and processes involved, and to encourage informed comment by the public and consideration of decision makers. The NOI was published in the Federal Register and the scoping period was conducted pursuant to 40 CFR 1501.7, 40 CFR 1506.6, and 59 IAM 3-H. Additional newspaper notices were published in the San Diego Business Journal and the San Diego Union-Tribune. All parties interested in the Project that have provided tier information, either signing in at the Scoping Meeting or via mail or email, will receive notification of the availability of the Draft EIS and subsequent public meetings. The public will have an additional opportunity to comment during the public review period of the Draft EIS. The Project and a range of alternatives will be discussed in the EIS, describing any alternatives eliminated from further analysis and alternatives evaluated to the same level as the identified Proposed Action.

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4 EIS SCHEDULE AND PUBLIC REVIEW

The current schedule anticipates that the Draft EIS will be available for public review in early 2019. The public review period for the Draft EIS will be 45 days. A public hearing on the Draft EIS will be held during the review period. After public comment on the Draft EIS, the BIA will publish a Final EIS. The BIA will wait at least 30 days after the Final EIS is released before issuing a decision on the Proposed Action.

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APPENDIX A

Notice of Intent

not for public use, would be located on East Ellis Road.

The following alternatives are considered in the DEIS: (1) Proposed Project; (2) Reduced Intensity Alternative; (3) Non-Gaming Alternative; (4) Custer Site Alternative and (5) No Action/No Development. Environmental issues addressed in the DEIS include geology and soils, water resources, air quality, biological resources, cultural and paleontological resources, socioeconomic conditions (including environmental justice), transportation and circulation, land use, public services, noise, hazardous materials, aesthetics, cumulative effects, and indirect and growth-inducing effects.

Locations where the DEIS is available for review: The DEIS will be available for review at the Fruitport Public Library located at 47 Park St., Fruitport, Michigan 49415, and online at *www.littlerivereis.com.* To obtain a compact disk copy of the DEIS, please provide your name and address in writing to Mr. Felix Kitto, Bureau of Indian Affairs, Midwest Regional Office. Contact information is listed in the **FOR FURTHER INFORMATION CONTACT** section of this notice. Individual paper copies of the DEIS will be provided only upon payment of applicable printing expenses by the requestor for the number of copies requested.

Public comment availability: Comments, including names and addresses of respondents, will be available for public review at the BIA address shown in the **ADDRESSES** section, during regular business hours, 8 a.m. to 4:30 p.m., Monday through Friday, except holidays. Before including your address, phone number, email address, or other personal identifying information in your comment, you should be aware that your entire comment—including your personal identifying information—may be made publicly available at any time. While you can ask in your comment that your personal identifying information be withheld from public review, the BIA cannot guarantee that this will occur.

Authority: This notice is published pursuant to Sec. 1503.1 of the Council of Environmental Quality Regulations (40 CFR parts 1500 through 1508) and Sec. 46.305 of the Department of the Interior Regulations (43 CFR part 46), implementing the procedural requirements of the NEPA of l969, as amended (42 U.S.C. 4371, *et seq.*), and is in the exercise of authority delegated to the Assistant Secretary—Indian Affairs by 209 DM 8.

Dated: November 9, 2018.

Tara Sweeney,

Assistant Secretary—Indian Affairs.

[FR Doc. 2018–25411 Filed 11–20–18; 8:45 am]

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DEPARTMENT OF THE INTERIOR

Bureau of Indian Affairs

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Notice of Intent To Prepare an Environmental Impact Statement for the Proposed Campo Wind Energy Project, San Diego, California

AGENCY: Bureau of Indian Affairs, Interior.

ACTION: Notice of intent.

SUMMARY: This notice advises the public that the Bureau of Indian Affairs (BIA), as lead agency, with the Campo Band of Diegueno Mission Indians of the Campo Indian Reservation (Tribe) as a cooperating agency, intends to gather information necessary for preparing an Environmental Impact Statement (EIS) for the proposed Campo Wind Project, located on the Campo Indian Reservation (Reservation) in southeastern San Diego County, approximately 60 miles east of San Diego, California. Construction of the Campo Wind Project is subject to BIA approval of a lease and sublease, which, as proposed, is a major Federal action under the National Environmental Policy Act of 1969 (NEPA), as amended. A brief description of the proposed action is provided below in the **SUPPLEMENTARY INFORMATION** section. This notice also announces a public scoping meeting to identify potential issues, concerns, and alternatives to be considered in the EIS. The scoping process will include notice to the public and Federal, State, local, and Tribal agencies of the proposed action.

DATES: Written comments on the scope and implementation of this proposal must arrive by 11:59 p.m. on December 21, 2018. The date and location of the public hearing on the EIS will be announced at least 15 days in advance through a notice to be published in local newspapers (The San Diego Union Tribune and The San Diego Business Journal) and online at: *www.campowind.com.*

ADDRESSES: The public may mail or hand-carry written comments to Ms. Amy Dutschke, Regional Director, Bureau of Indian Affairs, 2800 Cottage Way, Sacramento, California 95825. You may also submit comments through email to Mr. Dan (Harold) Hall, Acting Chief, Division of Environmental, Cultural Resource Management and Safety, Bureau of Indian Affairs, at *harold.hall@bia.gov.* More information can be found in the **SUPPLEMENTARY INFORMATION** section of this notice.

Please include the commenter's name, title, return address, and ''EIS Scoping Comments, Campo Wind Project, San Diego County, California,'' on the first page of the written comments. The scoping meeting will be held at Campo Indian Reservation Tribal Hall, 36190 Church Road (BIA Road 10), Campo, California 91906.

FOR FURTHER INFORMATION CONTACT: Mr. Dan (Harold) Hall Acting Chief, Division of Environmental, Cultural Resource Management and Safety, Bureau of Indian Affairs, by telephone at (916) 978–6041, or by email at *harold.hall@bia.gov.*

SUPPLEMENTARY INFORMATION:

Project Description

BIA approval is required for a lease and sublease to build and operate a commercial wind power generation facility capable of generating up to 252 megawatts (MW) of electricity.

The project would include the generation of up to 252 MW consisting of up to 60 turbines. The project study area covers approximately 2,200 acres on the Campo Indian Reservation. The total area that would be disturbed by the project would be substantially less. The turbines proposed for the project would range from 2.5 MW to 4.2 MW in maximum output rating per turbine, tubular steel towers, with a rotor diameter of approximately 450 feet, a hub height of approximately 361 feet, and a total height of turbine (highest point) of approximately 586 feet. Each turbine would be set on a concrete foundation. Turbines would be connected by an underground electrical collection system to a project collector substation. The collector substation would be sited on approximately 2 acres and would consist of a graveled, fenced area containing transformer and switching equipment and an area for vehicle parking. A new 230 kV overhead generation transmission line would be constructed, on the Campo Indian Reservation and partially outside on private lands, from the project collector substation on the Reservation to a San Diego Gas & Electric (SDG&E) substation/switchyard that would be constructed on private lands adjacent to the Sunrise Powerlink northeast of the Reservation. The SDG&E substation/switchyard and related transmission line improvements will be subject to approval by the County of San Diego, California, Public Utilities Commission (CPUC) and the BIA. Other required facilities, all located within the Reservation, would include: Up to three permanent meteorological towers; temporary material laydown areas during construction; temporary staging and construction trailer areas; an operations and maintenance building; underground cabling; telecommunications; new access roads and improvements to portions of existing roads; and a temporary concrete batch plant. The wind power generation facility would operate year-round for a minimum of 25 years.

The EIS will analyze the potential environmental impacts of the construction and operation of a proposed wind generation facility, including access roads, a collector substation, as well as a substation/switchyard and transmission facilities. The EIS will be prepared in accordance with NEPA (42 U.S.C. 4321 *et seq.*); the Council on Environmental Quality (CEQ) regulations (40 CFR parts 1500–1508); Department of the Interior regulations (43 CFR part 46); and the BIA NEPA Handbook (59 IAM 3–H) and will also be compliant with the California Environmental Quality Act in accordance with Public Resources Code section 21083.7. A reasonable range of alternatives to the proposed action including a no-action alternative, will be analyzed in the EIS. The range of issues and alternatives included will be based on comments and information received during the scoping process. This notice initiates the public scoping process to identify alternatives and relevant issues associated with the proposed project.

Directions for Submitting Public Comments

During the public scoping meetings, the public may submit written and verbal comments. Verbal comments given at the scoping meetings will have the same merit as written comments and will be addressed equally. The public may mail or hand-carry written comments to Ms. Amy Dutschke, Regional Director, Bureau of Indian Affairs, 2800 Cottage Way, Sacramento, California 95825. Please include the commenter's name, title, return address and ''EIS Scoping Comments, Campo Wind Project, San Diego County, California,'' on the first page of the written comments.

Public Availability of Comments

Comments, including names and addresses of respondents, will be available for public review at the BIA address shown in the **ADDRESSES** section of this notice, during business hours, 8 a.m. to 4:30 p.m., Monday through Friday, except holidays. Individual respondents may request confidentiality. If a commenter wishes us to withhold commenter's name and/or address from public review or from disclosure under the Freedom of Information Act, the commenter must state this prominently at the beginning of the written comment. Such requests will be honored to the extent allowed by the law, however there is a possibility that the comment(s) may be made publicly available at any time.

Authority

This notice is published in accordance with sections 1501.7 (Scoping), 1506.6 (Public involvement), and 1508.22 (Notice of Intent) of the CEQ Regulations (40 CFR parts 1500 through 1508) and section 46.305 of the Department of the Interior Regulations (43 CFR part 46), implementing the procedural requirements of NEPA, as amended (42 U.S.C. 4321 *et seq.*), and is in the exercise of authority delegated to the Assistant Secretary—Indian Affairs by 209 DM 8.

Dated: November 9, 2018.

Tara Sweeney,

Assistant Secretary—Indian Affairs.

[FR Doc. 2018–25412 Filed 11–20–18; 8:45 am]

BILLING CODE 4337–15–P

DEPARTMENT OF THE INTERIOR

Bureau of Land Management

[19X.LLAK930000.L13100000.DS0000]

Notice of Intent To Prepare an Integrated Activity Plan and Environmental Impact Statement for the National Petroleum Reserve in Alaska

AGENCY: Bureau of Land Management, Interior.

ACTION: Notice of intent.

SUMMARY: In accordance with the Naval Petroleum Reserves Production Act of 1976, as amended, the Bureau of Land Management (BLM) Alaska State Office, Anchorage, Alaska, intends to prepare a new Integrated Activity Plan and Environmental Impact Statement (IAP/EIS) for BLM-managed lands within the National Petroleum Reserve in Alaska (NPR–A). By this notice, the BLM is announcing the beginning of the Environmental Impact Statement (EIS) scoping process to solicit public comments and identify issues.

DATES: Comments on relevant issues that will influence the scope of the EIS for the NPR–A IAP/EIS project may be submitted in writing until January 7, 2019. The BLM will also provide opportunities for public participation during scoping meetings with appropriate public notice. The date(s) and location(s) of scoping meetings will be announced in advance through local media, newspapers, and the BLM website at: *www.blm.gov/alaska.*

In order to be considered for the Draft IAP/EIS, all comments must be received prior to the close of the 45-day scoping period. Federal, State or local agencies, or tribes who are interested in serving as a cooperating agency for the development of the IAP/EIS are asked to submit such requests to the BLM.

ADDRESSES: You may submit comments on issues related to the proposed NPR–A IAP/EIS project by any of the following methods:

- *Online: http://www.blm.gov/alaska/NPR-A-IAP-EIS.*
- *Fax:* (907) 271–5479.
- *Mail:* NPR–A IAP/EIS Scoping Comments, 222 West 7th Avenue, Mailstop #13, Anchorage, AK 99513.

The 2013 IAP/EIS ROD can be downloaded from the BLM's website at *www.blm.gov/alaska,* and you can view hard copies at the BLM Alaska Public Information Center (''Public Room''), Arctic District Office, 222 University Avenue, Fairbanks, Alaska, and at the BLM Alaska Public Information Center (''Public Room''), Alaska State Office, 222 West 8th Avenue, Anchorage, Alaska.

FOR FURTHER INFORMATION CONTACT: Stephanie Rice; Planning and Environmental Coordinator, 907–271–3202, *srice@blm.gov.* You may also request to be added to the mailing list. People who use a telecommunications device for the deaf (TDD) may call the Federal Relay Service (FRS) at 1–800–877–8339 to contact the above individual during normal business hours. The FRS is available 24 hours a day, seven days a week, to leave a message or question with the above individual. You will receive a reply during normal business hours.

SUPPLEMENTARY INFORMATION: This notice initiates the public scoping process for the EIS. Comments regarding management decisions, resources to be addressed, and issues for analysis will assist the BLM in defining the proposed actions and alternatives for the NPR–A IAP/EIS.

The Naval Petroleum Reserves Production Act (42 U.S.C. 6501), as amended, excludes the NPR–A from the application of Section 202 of the Federal Land Policy and Management Act (43 U.S.C. 1701), as amended, which is the

APPENDIX B

Public Notice of Scoping Meeting

CERTIFICATE OF PUBLICATION

In The Matter OF
Dudek-Campo Meeting

NOTICE OF PUBLIC SCOPING MEETING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

SUMMARY: This notice advises the public that the Bureau of Indian Affairs (BIA), as lead agency, with the Campo Band of Diegueno Mission Indians (Tribe) and the County of San Diego (County) as cooperating agencies, intends to hold a **Public Scoping Meeting** to gather information necessary for preparing a Draft Environmental Impact Statement (DEIS) for the proposed Campo Wind Project (project), located on the Campo Indian Reservation (Reservation) in southeastern San Diego County, approximately 60 miles east of the City of San Diego, California. Construction of the Campo Wind Project is subject to BIA approval of a lease and sublease, which, as proposed, is a major Federal action under the National Environmental Policy Act of 1969 (NEPA), as amended.

The project would include the generation of up to 252 MW consisting of up to 60 turbines. The turbines proposed for the project would range from 2.5 MW to 4.2 MW in maximum output rating per turbine, tubular steel towers, with a rotor diameter of approximately 450 feet, a hub height of approximately 361 feet, and a total height of turbine (highest point) of approximately 586 feet. Each turbine would be set on a concrete foundation. Turbines would be connected by an underground electrical collection system to a project collector substation. A new 230 kV overhead generation transmission line would be constructed partially on the Reservation and partially on private lands, from the project collector substation on the Reservation to a San Diego Gas & Electric (SDG&E) substation/switchyard that would be constructed on private lands adjacent to the Sunrise Powerlink northeast of the Campo Indian Reservation. The SDG&E substation/switchyard and related transmission line improvements will be subject to approval by the County, California Public Utilities Commission (CPUC), and the BIA.

DATE: The public scoping meeting will be held on December 6, 2018, from 6 p.m. until 9 p.m.

LOCATION: The December 6, 2018, meeting will be held at Campo Indian Reservation Tribal Hall, 36190 Church Road (BIA Road 10), Campo, California.

FOR FURTHER INFORMATION CONTACT: To request additional information about this notice, please contact Mr. Dan (Harold) Hall Acting Chief, Division of Environmental, Cultural Resource Management and Safety, Bureau of Indian Affairs, by telephone at (916) 978-6041, or by email at harold.hall@bia.gov.
Please also visit http://www.CampoWind.com

Publication Date: 11/26/2018

I, L. L. Lauridsen, hereby certify that The San Diego Business Journal is a weekly newspaper of general circulation within the provisions of the Government Code of the State of California, printed and published in The/ County of San Diego, State of California, and the City of San Diego

Public Notice

To which this certificate is annexed is a true and correct copy published in said newspaper on

11/26/2018

I certify under penalty of perjury that the foregoing is true and correct.
Dated at San Diego, California November 26 2018.

*The San Diego Business Journal was Judicated for Publication on 11/14/86 in San Diego County, Case Number # 572404

The San Diego Union-Tribune

PROOF of Publication

Bill To:
Matt Valerio - CU80023064
605 3rd St
Encinitas,CA 92024-3513

STATE OF ILLINOIS
COUNTY OF Cook

The Undersigned, declares under penalty of perjury under the laws of the State of California: That he/she is and at all times herein mentioned was a citizen of the United States, over the age of twenty-one years, and that he/she is not a party to, nor interested in the above entitled matter; that he/she is Chief Clerk for the publisher of

San Diego Union-Tribune

a newspaper of general circulation, printed and published daily in the City of San Diego, County of San Diego, and which newspaper is published for the dissemination of local news and intelligence of a general character, and which newspaper at all the times herein mentioned had and still has a bona fide subscription list of paying subscribers, and which newspaper has been established, printed and published at regular intervals in the said City of San Diego, County of San Diego, for a period exceeding one year next preceding the date of publication of the notice hereinafter referred to, and which newspaper is not devoted to nor published for the interests, entertainment or instruction of a particular class, profession, trade, calling, race, or denomination, or any number of same; that the notice of which the annexed is a printed copy, has been published in said newspaper in accordance with the instruction of the person(s) requesting publication, and not in any supplement thereof on the following dates, to wit:

November 21, 2018

I certify under penalty of perjury under the laws of the State of California that the foregoing is true and correct.

Dated in the City of Chicago, State of Illinois
on this 21st of November 2018.

Stefanie Sobie
San Diego Union-Tribune
Legal Advertising

Proof of Publication of

See Attached

5997525

The San Diego Union-Tribune

Bill To:
Matt Valerio - CU80023064
605 3rd St
Encinitas,CA 92024-3513

Sold To:
Matt Valerio - CU80023064
605 3rd St
Encinitas,CA 92024-3513

NOTICE OF PUBLIC SCOPING MEETING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

SUMMARY: This notice advises the public that the Bureau of Indian Affairs (BIA), as lead agency, with the Campo Band of Diegueno Mission Indians (Tribe) and the County of San Diego (County) as cooperating agencies, intends to hold a Public Scoping Meeting to gather information necessary for preparing a Draft Environmental Impact Statement (DEIS) for the proposed Campo Wind Project (project), located on the Campo Indian Reservation (Reservation) in southeastern San Diego County, approximately 60 miles east of the City of San Diego, California. Construction of the Campo Wind Project is subject to BIA approval of a lease and sublease, which, as proposed, is a major Federal action under the National Environmental Policy Act of 1969 (NEPA), as amended.

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5997525

The San Diego Union-Tribune

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Please also visit http://www.CampoWind.com

APPENDIX C
Public Comments List

Campo Wind NOI Tracking Sheet
NOI Commenter Index

Comment Letter Designation	Commenter	Address (if available)	Email (if available)	Date
Federal Agency (F) (e.g. USFWS)				
F1	Environmental Protection Agency (EPA) - Karen Vitulano	2800 Cottage Way Sacramento, California 95825	vitulano.karen@epa.gov	12/20/2018
F2	Duncan Hunter - US House of Representatives 50th District	2429 Rayburn House Office Building, Washington, DC 20515		1/10/2019
Organizations (O)				
O1	Backcountry Against Dumps	PO Box 1275, Boulevard, CA 91905	tisdale.donna@gmail.com	12/20/2018
O2	Law Offices of Steven Volker - On Behalf of Backcountry Against Dumps	1633 University Avenue Berkeley, California 94703	svolker@volkerlaw.com	12/20/2018
O3	Boulevard Planning Group	PO Box 1275, Boulevard, CA 91905	tisdale.donna@gmail.com	12/20/2018
Individuals (I)				
I1	Nancy Good	PO Box 1165, Boulevard, CA	nancykgood@gmail.com ngood81173@aol.com	12/6/2018
I2	Charles Good	37649 Old Hwy 80, Boulevard, CA 91905		12/6/2018
I3	Benjamin Good	35252 Old Hwy 80, Pine Valley, CA 91905		12/6/2018
I4	Lisa Gover	36190 Church Rd, Suite 4, Campo, CA 91960	lgover@campo-nsn.gov	12/6/2018
I5	Byron Polen	PO Box 1124, Boulevard, CA	mtnnototrav@aol.com	12/6/2018
I6	Ron Cuero	4611 Kumeyaay Rd, Campo, CA 91906		12/6/2018
I7	Bradley Downes		bdownes@bdrlaw.com	12/6/2018
I8	Ralph Goff		rgoff@campo-nsn.gov	12/6/2018
I9	H. Paul	36670 Hwy 94, Campo, CA 91907		12/6/2018
I10	Annah Ceballos	37646 Williams Rd., Boulevard, CA 91905	aceballos0@aol.com	12/6/2018
I11	Donna & Ed Tisdale	PO Box 1275, Boulevard, CA 91905	tisdale.donna@gmail.com	12/6/2018
I12	Ron Hynum	39548 Opalocka Rd, Boulevard, CA 91905	rhynum@camft.com	12/6/2018
I13	Carmen Tsorie	37855 High Pass, Boulevard, CA 91905	wildhorsesrunning@yahoo.com	12/6/2018
I14	Michelle Cuero	4611 Kumeyaay Rd, Campo, CA 91906	rscuero@gmail.com	12/6/2018
I15	Ken Wagner	11455 El Camino Real, San Diego, CA 92130		12/6/2018
I16	Ashley Richmond	11455 El Camino Real, San Diego, CA 92130		12/6/2018
I17	Clifford & Concha Caldwell	PO Box 710, El Centro, CA 92244	pincal0@sbcglobal.net	12/6/2018
I18	Benjamin A.	35252 Old Hwy 80, Pine Valley, CA 91905	allgoodworks@gmail.com	12/6/2018
I19	Petra Campos	4801 Kumeyaay Rd, Campo, CA 91906	petracampos6@gmail.com	12/6/2018
I20	Steven Cuero	36810 Church Rd, Campo, CA		12/6/2018
I21	Michele Strand	PO Box 1424, Boulevard, CA	michelestrand@yahoo.com	12/6/2018
I22	Greg Kazmer	5510 Overland Dr, San Diego, CA 92123	gregory.kazmer@sdcounty.ca.gov	12/6/2018
I23	Marcus Cuero	36616 Hwy 94, Campo, CA 91906	madone05@gmail.com	12/6/2018
I24	Barranco Z.	1576 Tierra Del Sol, Boulevard, CA 91905	themightyq8@gmx.com	12/6/2018
I25	Katherine Edgerley		kedgerle@uw.edu	12/3/2018
I26	Evangeline Adkins	2492 Tierra Heights Rd, Boulevard, CA 91905	evangelineadkins@yahoo.com	12/20/2018
I27	Jeff Morrison	P.O. Box 1116, Boulevard, CA 91905	eastcountyproperty@yahoo.com	12/19/2018
I28	Heather Robbins	2492 Tierra Heights Rd, Boulevard, CA 91905		12/20/2018
I29	Robert Laguna & Rose Tapia	1237 Tierra Real Lane, Boulevard, CA 91905	rosetapia4444@gmail.com	12/19/2018
I30	Aaron Peterson		agpblvd@yahoo.com	12/21/2018

I31	Earl Goodnight	1902 Jewel Valley Lane, Boulevard, CA 91905		12/20/2018
I32	Javier Beltran	PO Box 2604, Alpine, CA 91903		12/17/2018
I33	Lorrie & Mark Ostrander	43577 Old Hwy 80, Jacumba, CA 91934		12/13/2018
I34	Marie & Scott Morgan	2912 Ribbonwood Rd, Boulevard, CA 91905	smorgy@hughes.net	12/21/2018
I35	Dennis Largo	33651 Hwy 94		1/28/2019
I36	Andrea Najera	36500 Church Rd, Campo, CA, 91906		1/28/2019
I37	Dan Mason	38300 Manzanita Rd, Boulevard, CA, 91905		12/18/2018
I38	Georgina Boudreau	36510 Church Rd, Campo, CA, 91906		12/10/2018
I39	Juanita Batey	36510 Church Rd, Campo, CA, 91906		12/20/2018
I40	Andy and Teresa DeGroot		teresa91905@icloud.com	12/18/2018
I41	Joyre Largo	4611 Kumeyaay Rd		12/19/2018
I42	Linda Quihuis	36510 Church Rd, Campo, CA, 91906		12/18/2018
I43	Monica Garcia	294 Shasta St #A, C.V, CA, 91910		12/11/2018
I44	Greg Montegna	8043 Hemingway, San Diego, CA, 82122		12/11/2018
I45	Rosario Valdez	2515 Camino del Rio St #240, San Diego, CA, 92108		12/13/2018
I46	Estrella Orozco	3837 Wabash Ave #6, San Diego, CA, 92104		12/13/2018
I47	Rita Ruiz	1317 5th Ave, San Diego, CA, 92108		12/13/2018
I48	Phillip Lowe	37515 Moon Valley Rd, Boulevard, CA, 91905		12/21/2018
I49	Gary Cogbill	38390 Old Hwy 80		12/14/2018
I50	Jennifer Schurb	2246 Tierra Heights Rd		12/14/2018
I51	Robert Tucker			12/16/2018
I52	Michele P	P.O Box 1042		12/16/2018
I53	Robert Minton	P.O Box 1304, Boulevard, CA, 91905		12/16/2018
I54	D. Shields	P.O Box 1043, Boulevard, CA, 91905		12/16/2018
I55	Pete Champ	P.O Box 1211, Boulevard, CA, 91905		12/16/2018
I56	Fred Chavez	P.O Box 1409, Boulevard, CA, 91905		12/16/2018
I57	Audra Burgio	387103 Ahavella Rd, Boulevard, CA, 91905		12/16/2018
I58	Linda Shannon	P.O Box 1527, Boulevard, CA, 91905		12/16/2018
I59	Sharon Madsen	38232 Tierra Real Rd, Boulevard, CA, 91905		12/16/2018
I60	Gerald Madsen	38233 Tierra Real Rd, Boulevard, CA, 91905		12/16/2018
I61	Rose Tapia	1237 Tierra Real Rd, Boulevard, CA 91905		12/16/2018
I62	Frank Jones	38204 Tierra Real Rd, Boulevard, CA, 91905		12/16/2018
I63	Nalin Flaman	38202 Tierra Real Rd, Boulevard, CA, 91905		12/16/2018
I64	William Swycaffer	38220 Tierra Real Rd, Boulevard, CA, 91905		12/16/2018
I65	Michele Swycaffer	38220 Tierra Real Rd, Boulevard, CA, 91905		12/16/2018
I66	Teresa Briggs	1310 Tierra Real Rd, Boulevard, CA, 91905		12/16/2018
I67	Steven Briggs	1310 Tierra Real Rd, Boulevard, CA, 91905		12/16/2018
I68	Monica Albai	P.O Box 1045, Tierra Real Rd, Boulevard, CA, 91905		12/16/2018
I69	Marty K	P.O Box 1401, Tierra Real Rd, Boulevard, CA, 91905		12/17/2018
I70	Tracy Tisdale	P.O Box 961, Boulevard, CA, 91905		12/21/2018
I71	Jason Fordyce	P.O Box 1045, Tierra Real Rd, Boulevard, CA, 91905		12/16/2018
I72	William F	37675 Moon Valley Rd, Boulevard, CA, 91905		12/16/2016
I73	Lonelei Howard	1601 Jewel Valley Rd		12/15/2018
I74	Glenn Howard	1601 Jewel Valley Rd		12/16/2018
I75	Deborah Shaw	1605 Jewel Valley Rd		12/16/2018
I76	Michelle Daubach	39954 Ribbonwood Rd, Boulevard, CA, 91905		12/16/2018
I77	Tammy Daubach	39954 Ribbonwood Rd, Boulevard, CA, 91905		12/16/2018
I78	Stan Budderbohn	37341 Hwy 94, Boulevard, CA, 91905		12/16/2018
I79	Larry Douglas	38511 Alta Vega Rd		12/15/2018
I80	Paul Unmack			12/15/2018
I81	Dustin Walker	39211 Clements St		12/15/2018
I82	John Dolan	38204 Tierra Real Rd, Boulevard, CA, 91905		12/16/2018
I83	Willy Shaw	40 E Restwood Rd		12/16/2018
I84	Pamela Gay	1975 Ribbonwood Rd, Boulevard, CA, 91905		12/16/2018
I85	Richard Dart			12/16/2018
I86	Patricia Grib	39605 Old Hwy 80, Boulevard, CA, 91905		12/14/2018
I87	Gina Butler	2738 Ribbonwood Rd, Boulevard, CA, 91905		12/15/2018
I88	Rex Butler	2738 Ribbonwood Rd, Boulevard, CA, 91905		12/15/2018
I89	David Elliot	P.O Box 937, Boulevard, CA, 91905		12/15/2018
I90	William Hernandez	P.O Box 1575, Boulevard, CA, 91905		12/15/2018
I91	Frank Davoli	P.O Box 1180, Boulevard, CA, 91905		12/15/2018
I92	Walt Henderson	P.O Box 1093, Boulevard, CA, 91905		12/15/2018
I93	Jeff M	2945 Ribbonwood Rd, Boulevard, CA, 91905		12/15/2018
I94	Rebecca Mauris	2945 Ribbonwood Rd, Boulevard, CA, 91905		12/15/2018
I95	Alysen Genty	P.O Box 1575, Boulevard, CA, 91905		12/15/2018
I96	Chris B	38763 Alta Vega Rd		12/15/2018
I97	Kevin LaClair	39548 Opalocka Rd, Boulevard, CA 91905		12/17/2018
I98	Travis Polen	P.O Box 1124, Boulevard, CA, 91905		12/17/2018
I99	Kayce Holmgren	2537 Angel Dr, Boulevard, CA, 91905		12/19/2018
I100	William Holmgren	2537 Angel Dr, Boulevard, CA, 91905		12/19/2018
I101	Heather Schwarz	964 Tierra De Luna, Boulevard, CA, 91905		12/19/2018
I102	Brad Schwarz	964 Tierra De Luna, Boulevard, CA, 91905		12/19/2018
I103	Christina Vickers	44640 Calexico Ave, Boulevard, CA, 91905		12/20/2018
I104	Anna Holmgren	2537 Angel Dr, Boulevard, CA, 91905		12/20/2018

I105	Jerry W	39557 Old Hwy 80, Boulevard, CA, 91905	12/20/2018
I106	Ferney Obeso	39537 Old Hwy 80, Boulevard, CA, 91905	12/20/2018
I107	Jacqueline R	1158 Tierra Del Sol Rd, Boulevard, CA, 91905	12/20/2018
I108	Joseph Long	1158 Tierra Del Sol Rd, Boulevard, CA, 91905	12/20/2018
I109	Christina Rodrigez	37839 Moon Valley Rd, Boulevard, CA, 91905	12/20/2018
I110	Amanda Jackson	1158 Tierra Del Sol Rd, Boulevard, CA, 91905	12/20/2018
I111	Jeremy Long	1158 Tierra Del Sol Rd, Boulevard, CA, 91905	12/20/2018
I112	Frances Lomely	37839 Moon Valley Rd, Boulevard, CA, 91905	12/20/2018
I113	Chris Rodrigez	37839 Moon Valley Rd, Boulevard, CA, 91905	12/20/2018
I114	Russell Harris	37748 Tierra Estrella Rd, Boulevard, CA, 91905	12/20/2018
I115	Donna Anselm	37748 Tierra Estrella Rd, Boulevard, CA, 91905	12/20/2018
I116	Jeanie Lewis	686 Tierra Del Sol Rd, Boulevard, CA, 91905	12/20/2018
I117	Mary Ayerra	664 Tierra Del Sol Rd, Boulevard, CA, 91905	12/20/2018
I118	Ned Tibbetts	664 Tierra Del Sol Rd, Boulevard, CA, 91905	12/20/2018
I119	Walt Bayless	510 Tierra Del Sol Rd, Boulevard, CA, 91905	12/20/2018
I120	Marilyn Polen	512 Tierra Del Sol Rd, Boulevard, CA, 91905	12/20/2018
I121	Adriana Polen	1678 Maryjoe Ln, Boulevard, CA, 91905	12/20/2018
I122	William Patrick	P.O Box 959 Boulevard, Ca, 91905	12/21/2018
I123	Debi Forsberg	1621 Jewel Valley Rd, Boulevard, CA, 91905	12/20/2018
I124	Michael Forsberg	1621 Jewel Valley Rd, Boulevard, CA, 91905	12/20/2018
I125	Amy Weisiger	39235 Hwy 94, Boulevard, CA, 91905	12/20/2018
I126	Debs Weisiger	39235 Hwy 94, Boulevard, CA, 91905	12/20/2018
I127	Robert Morgan	2912 Ribbonwood Rd, Boulevard, CA 91905	12/20/2018
I128	David Shannon	2587 Ribbonwood Rd, Boulevard, CA, 91905	12/20/2018
I129	Debbie Moran	39545 Clements St, Boulevard, CA, 91905	12/20/2018
I130	Michael Moran	39545 Clements St, Boulevard, CA, 91905	12/20/2018
I131	Irene Centos	2233 Tierra Heights Rd, Boulevard, CA, 91905	12/20/2018
I132	Joseph Flores	38808 Old Hwy 80, Boulevard, CA, 91905	12/20/2018
I133	James Blanke	38808 Old Hwy 80, Boulevard, CA, 91905	12/20/2018
I134	Larry Monday	2496 Tierra Heights Rd, Boulevard, CA, 91905	12/20/2018
I135	Priscilla Monday	2496 Tierra Heights Rd, Boulevard, CA, 91905	12/20/2018
I136	Skylar Middlebrook	P.O Box 1077, Boulevard, CA, 91905	12/15/2018
I137	Erin Aldridge		12/18/2018
I138	Katie Webb	19880 UCS Ranch Rd, Boulevard, CA, 91905	12/19/2018
I139	Alex S		12/19/2018
I140	Jenene Lambert	576 Tierra Del Sol Rd, Boulevard, CA, 91905	12/20/2018
I141	Dwight Swinland	38763 Alta Vega Rd, Boulevard, CA, 91905	12/20/2018

EIR/EIS Topics	Other/Notes
Noise, Water Resources, Air Quality, GHG Emissions, Biological Resources, Hazards and Hazardous Materials, Aesthetics, Cumulative Impacts, Alternatives	
Cumulative Projects	
Biological Resources, Noise, GHG Emissions, Hydrology and Water Quality, Hazards and Hazardous Materials, Aesthetics, Socioeconomic Conditions, Alternatives	Brings up some legal concerns. Also includes a list of exhibits to substantiate reasoning for requested impact analysis.
Socioeconomic Conditions, Biological Resources, Hazards and Hazardous Materials, Alternatives	Included a bunch of scientific studies and non-CEQA related questions
Aesthetics, Noise, Hazards & Hazardous Materials, Biological Resources, Hydrology and Water Quality, Traffic and Transportation, Health and Safety, Cumulative Impacts	Form Letter
Aesthetics, Noise, Hazards & Hazardous Materials, Biological Resources, Hydrology and Water Quality, Traffic and Transportation, Health and Safety, Cumulative Impacts	Form Letter
Aesthetics, Noise, Hazards & Hazardous Materials, Biological Resources, Hydrology and Water Quality, Traffic and Transportation, Health and Safety, Cumulative Impacts	Form Letter
Socioeconomic Conditions & Environmental Justice	
Biological Resources, Noise, Aesthetics, Health and Safety, Hydrology and Water Quality,	Attached some independent studies about "noise and electrical pollution testing"
Aesthetics, Noise, Hazards & Hazardous Materials, Biological Resources, Hydrology and Water Quality, Traffic and Transportation, Health and Safety, Cumulative Impacts	Form Letter
Socioeconomic Conditions, Health and Safety	
	Applicant
	Applicant
	Supports Boulevard Planning Group's comments
	County of San Diego
Air Quality, Hazards and Hazardous Materials, Aesthetics, Noise, Historic & Cultural Resources	
Noise, Health and Safety, Hazards & Hazardous Materials, Aesthetics, Water Resources, Biological Resources, Cumulative Impacts	
Noise, Heath and Safety, Hazards & Hazardous Materials	
Noise, Health and Safety, Hazards & Hazardous Materials, Aesthetics, Water Resources, Biological Resources, Cumulative Impacts	

Aesthetics, Noise, Hazards & Hazardous Materials, Biological Resources, Hydrology and Water Quality, Traffic and Transportation, Health and Safety, Cumulative Impacts	Form Letter
Aesthetics, Biological Resources, Hazards and Hazardous Materials	
Biological Resources, Water Resources, Hazards and Hazardous Materials	
Noise, Aesthetics, Hazards and Hazardous Materials	
Health and Safety, Land Resources	
Socioeconomic Conditions	
Socioeconomic Conditions, Heath and Safety	
Aesthetics, Noise, Hazards & Hazardous Materials, Socioeconomic Conditions, Health and Safety	
Biological Resources, Noise	
Socioeconomic Conditions	
Aesthetics, Biological Resources, Health and Safety, Noise, Hydrology and Water Quality, Hazards and Hazardous Materials, Cumulative Impacts	
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APPENDIX D

Preliminary Information Package and Comment Letters

SCOPING MEETING

Campo Wind Project

December 6, 2018

6:00 PM

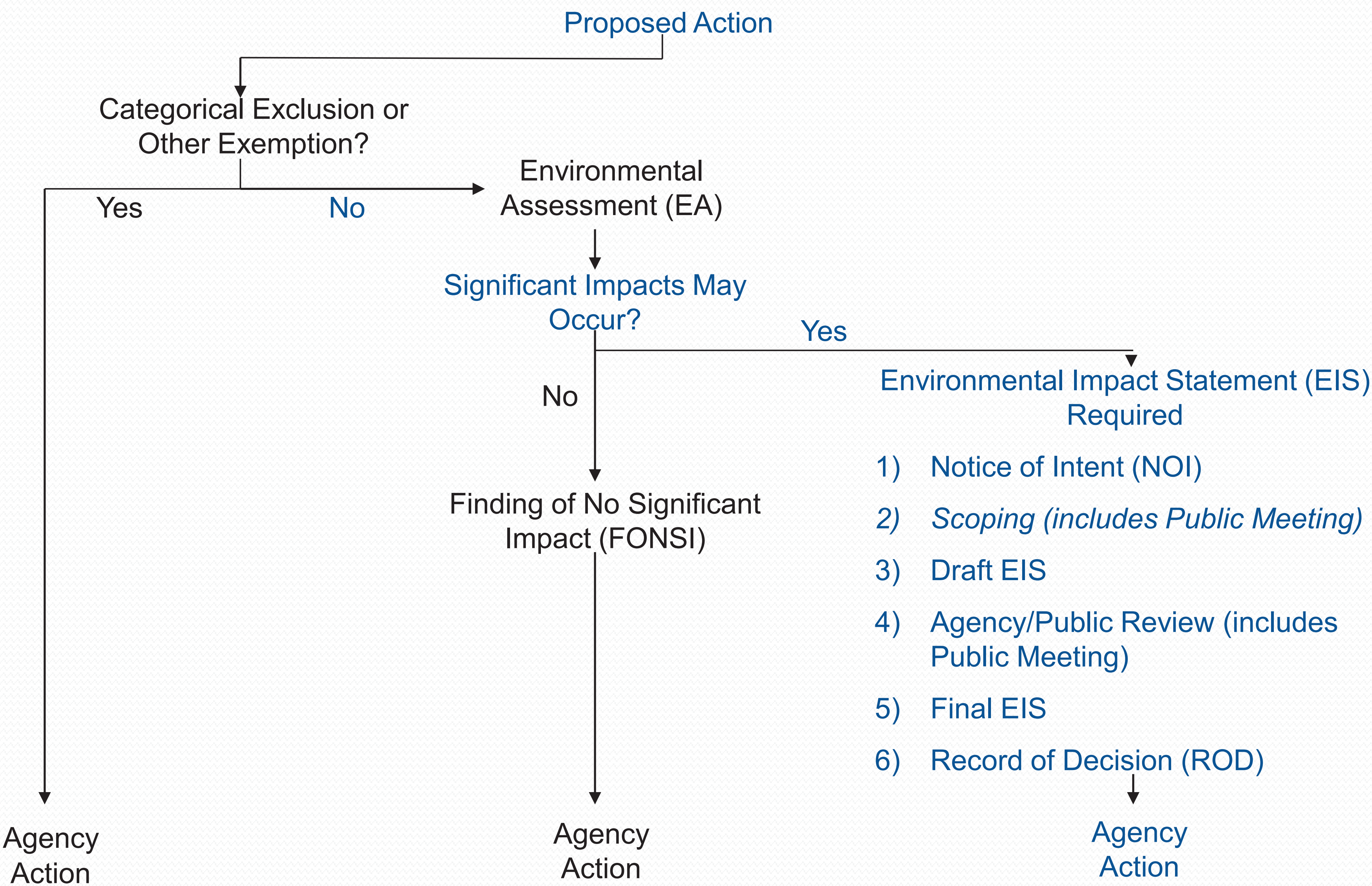
LEAD AGENCY: U.S. Department of the Interior, Bureau of Indian Affairs

WHEN IS NEPA REVIEW REQUIRED?

- National Environmental Policy Act (NEPA) review is required prior to taking a major federal action

- In this case, the proposed major federal action requested by the Campo Band of Diegueno Mission Indians (Campo Tribe) is approval of a lease of approximately 2,200 acres with TerraGen Development Company, LLC for the purpose of developing a renewable wind energy project

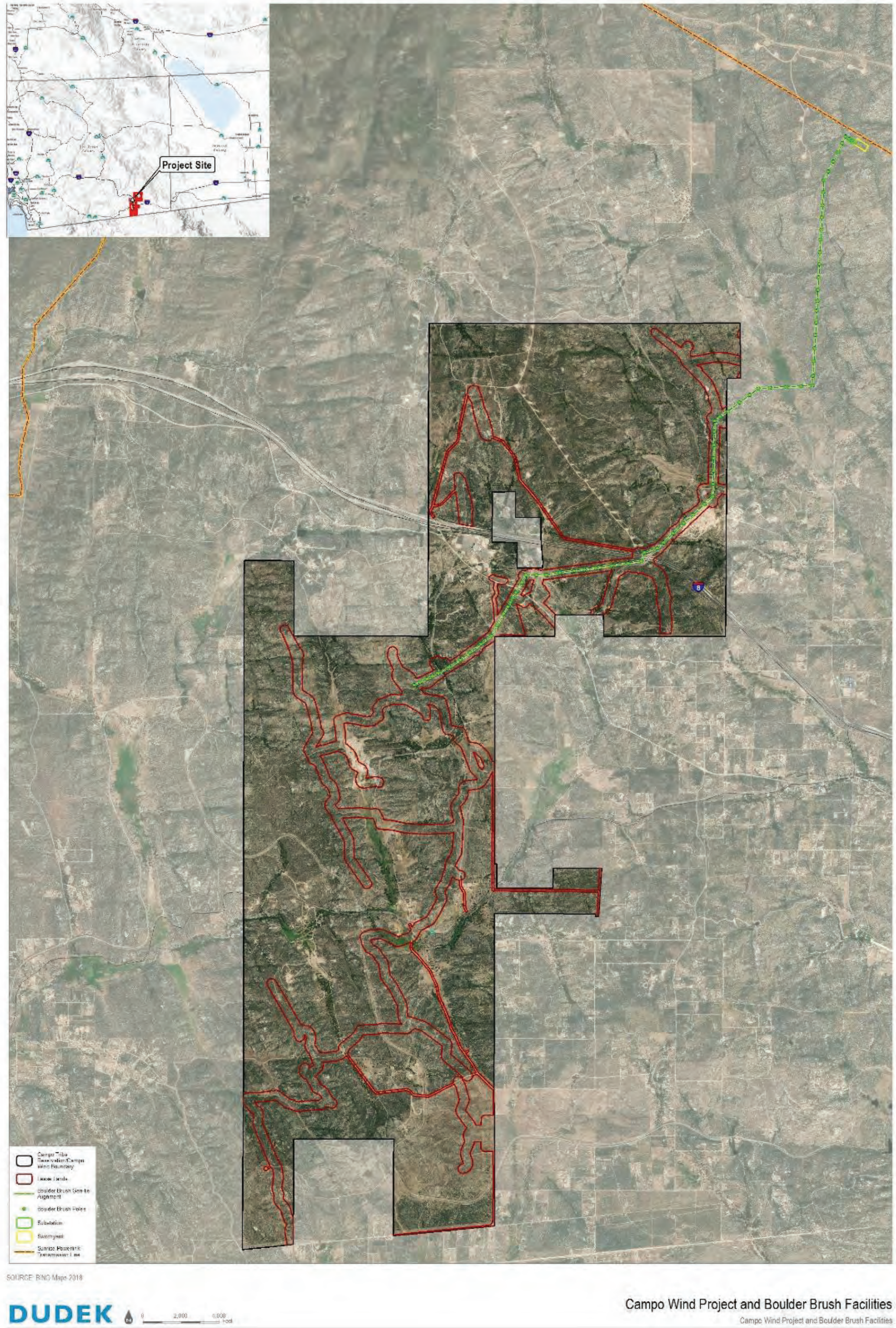
NEPA PROCESS OVERVIEW



PROPOSED ACTION

- Lease approval within San Diego County
- The Campo Tribe proposed to lease sovereign lands to TerraGen Development Company, LLC for the purpose of developing a renewable energy (wind) project
  - 2,200-acre lease area on the Campo Reservation within the eastern portion of San Diego County.
  - 60, 2.5-4.2 MW Wind Turbines
  - Approximately 252 MW of wind generated electricity
  - Generation Tie line to extend off-Reservation to connect to the Sunrise Powerlink

Project Location and Lease Lands



EIS PROCESS - Scoping

- Notice of Intent (NOI) published in the federal register on November 21, 2018, beginning the scoping process
- The NOI and all future NEPA documents will be posted online at *http://www.campowind.com*
- "Scoping" refers to the process by which lead agencies solicit input from the public and interested agencies on the nature and extent of issues and impacts to be addressed in the EIS and the methods by which they will be evaluated
- The scope of a document includes the extent of the action, the range of alternatives, and the types of impacts to be evaluated

ISSUES TO BE ANALYZED IN THE EIS

- Greenhouse Gas Emissions and Climate Change
- Water Resources
- Air Quality
- Noise
- Biological Resources
- Cultural Resources
- Traffic and Transportation
- Land Use
- Public Health and Environmental Safety
- Public Services and Utilities
- Socioeconomics and Environmental Justice
- Visual Resources/Aesthetics
- Indirect and Cumulative Effects

EIS PROCESS – Scoping Comments

- The scoping comment period ends December 21, 2018
- The scoping comment period, including this scoping meeting, provides the public with an opportunity to comment on the scope of the upcoming EIS
- All scoping comments, whether written or spoken at this meeting, will be considered equally by the BIA

EIS PROCESS – Scoping Report

- After the close of the scoping comment period, the BIA will prepare a Scoping Report that summarizes the comments received during the scoping period
- Each comment letter received and a transcript of this scoping meeting will be included in the Scoping Report
- The BIA will utilize the Scoping Report in preparing a Draft EIS

EIS PROCESS – Draft EIS

- The BIA will prepare a Draft EIS that analyzes the environmental impacts of the proposed action along with a reasonable range of alternatives
- The Draft EIS will be made available to the public for at least a 45 day review and comment period
- Another public meeting will be held during the Draft EIS review and comment period

EIS PROCESS – Final EIS and ROD

- After the public review/comment period on the Draft EIS has closed, the BIA will prepare a Final EIS
- The Final EIS will include responses to all substantive comments received on the Draft EIS
- When completed, the Final EIS will be made available to the public for review
- At least 30 days after the publication of the Final EIS, the BIA will issue a Record of Decision (ROD) that includes its decision on whether or not to approve the proposed action
- The ROD marks the end of the NEPA process

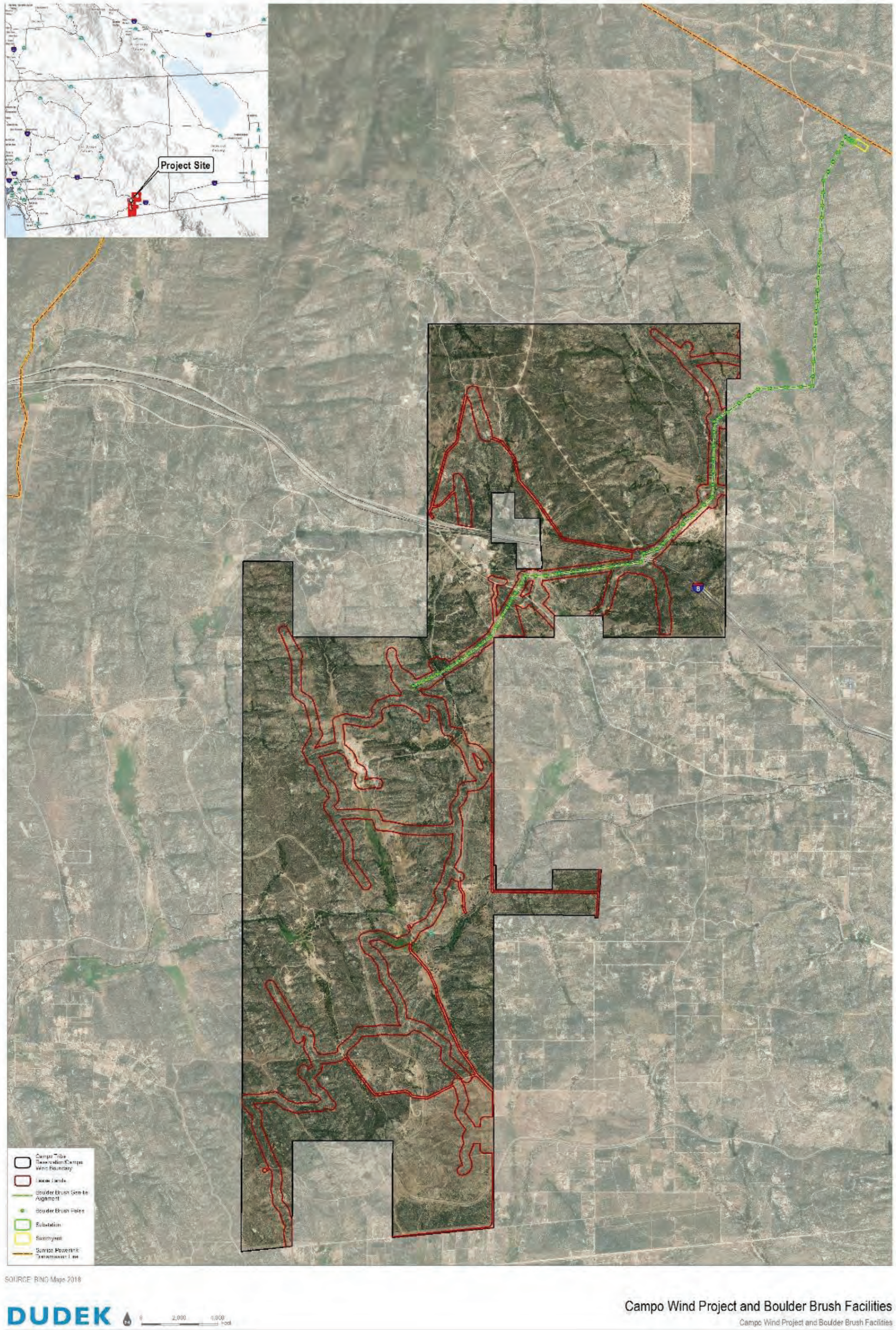
BIA CONTACT INFORMATION

You may mail, hand carry, or fax written comments to:
Ms. Amy Dutschke, Regional Director
Bureau of Indian Affairs, Pacific Regional Office
2800 Cottage Way
Sacramento, CA 95825

For further information contact:
Dan Hall, Bureau of Indian Affairs
Phone – (916) 978-6041

Also Visit: http://www.campowind.com

Public Comments



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105-3901

December 20, 2018

Ms. Amy Dutschke, Regional Director
Bureau of Indian Affairs
2800 Cottage Way
Sacramento, California 95825.

Subject: EPA Scoping Comments for the Proposed Campo Wind Energy Project, San Diego, California

Dear Ms. Dutschke:

The Environmental Protection Agency has reviewed the Notice of Intent (NOI) published on November 21, 2018 requesting comments on the Bureau of Indian Affairs (BIA) decision to prepare an Environmental Impact Statement (EIS) for subject project. Our comments are provided pursuant to the National Environmental Policy Act (NEPA), Council on Environmental Quality regulations (40 CFR Parts 1500-1508) and our NEPA review authority under Section 309 of the Clean Air Act.

The proposed project requires BIA approval for a lease and sublease to build and operate a commercial wind power generation facility on approximately 2,200 acres of the Campo Indian Reservation. The proposal consists of up to 60 turbines, ranging from 2.5 megawatts (MW) to 4.2 MW each, for the generation of up to 252 MW of electricity, and includes meteorological towers; temporary material laydown and staging areas; an operations and maintenance building; underground cabling; telecommunications; new access roads and improvements to existing roads; and a temporary concrete batch plant.

To assist in the scoping process for this project, we have identified several issues for your attention in the preparation of the EIS:

Alternatives Analysis

The alternatives analysis is the heart of the Environmental Impact Statement (40 CFR 1502.14). We recommend evaluating a reasonable range of alternatives, including options for reducing significant environmental impacts and additional mitigation not already included in the proposed action (40 CFR 1502.14 (f)). Reasonable alternatives could include: alternative project sites within the reservation; alternative configurations, capacities, and turbine types, sizes, and technologies; and alternative locations for facilities (office, operations and maintenance buildings) and material laydown areas. We recommend locating facilities on existing disturbed land, if applicable. Discuss the reasons for eliminating alternatives that are not evaluated, and describe the criteria used to determine the minimum project size that would be considered feasible for meeting the purpose and need.

The analyses in the DEIS should clearly distinguish impacts among alternatives. For example, quantify the number of individuals that could be impacted for each alternative (birds, bats, people) and characterize the intensity of the impact for each alternative. Quantify or specifically characterize the differences in impacts among the alternatives to the maximum extent possible. Present the environmental impacts of the alternatives in comparative form, preferably a table, to sharply define the issues and provide a clear basis for choice among options by the decision-maker and the public (40 CFR 1502.14). We recommend identifying the preferred alternative in the DEIS if it is known.

Mitigation Measures

Mitigation measures are often necessary for reducing impacts to resources, consistent with our National Environmental Policy, and NEPA requires a discussion of mitigation measures (40 CFR 1502.16 (h)). The DEIS should identify and discuss the mitigation measures that are being proposed as part of the project. An essential component of this discussion is an assessment of whether the proposed mitigation measures can be effective. It is important that mitigation measures are clearly identified and, when proposed, that BIA and the Tribe commit to their implementation. Identify the party responsible for implementation and indicate whether there is sufficient funding for mitigation. BIA and the Tribe should ensure that the developer adheres to mitigation commitments, monitors how they are implemented, and monitors the effectiveness of the mitigation. BIA or the Tribe should make information on mitigation monitoring available to the public, such as through its web site. We recommend consulting the Council on Environmental Quality's (CEQ) guidance on the appropriate use of mitigation and monitoring (available: https://www.energy.gov/nepa/downloads/appropriate-use-mitigation-and-monitoring-and-clarifying-appropriate-use-mitigated). The timeframe for the action should also be specified to ensure that the intended start date and duration of the mitigation commitment is clear.

Noise Impacts

The noise impact assessment should identify the significance threshold utilized in the impact assessment methodology. We note that EPA identified a goal of 55 A-weighted decibels (dBA) for outdoor residential areas to fully protect the public health and welfare.[1] We recommend using C-weighted noise metrics, as well as A-weighted metrics, to cover the low-frequency sounds often associated with wind turbines.

Potential health impacts from noise should be discussed. There is increasing evidence that noise impacts can have non-auditory health effects. A 2007 review article[2] that summarizes studies from the National Library of Medicine database on the adverse health effects of noise notes that long-term physical health effects have been linked to noise effects related to sleep disturbances, stress, and increased blood pressure, and can increase cardiovascular disease risk. These effects begin to be seen with long-term daily exposure to noise levels above 65 dB or with acute exposure to noise above 80-85 dB[3]. The World Health Organization recommends that, where noise is continuous, the equivalent sound pressure level should not exceed 30 dBA indoors if negative effects on sleep are to be avoided. When the noise is composed of a large proportion of low-frequency sounds, a still lower guideline value is recommended because low frequency noise can disturb rest and sleep even at low sound pressure levels.

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[1] *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety* (EPA, 1974). Available: http://www.nonoise.org/library/levels74/levels74.htm .

[2] Goines, Lisa RN and Hagler, Louis MD. 2007. "Noise Pollution: A Modern Plague", *Southern Medical Journal*: Volume 100 - Issue 3 - pp 287-294.

[3] Ibid, p. 290

Include noise estimates for schools that could be impacted under the alternatives and discuss potential effects of noise on school learning and academic achievement in children, as applicable. This could include referencing the acoustical performance criteria of the American National Standards Institute (ANSI) standard S12.60-2002.[4] For learning environments, the critical effects of noise are on speech interference, disturbance of information extraction (e.g. comprehension and reading acquisition), message communication and annoyance. Per the ANSI Standard, to be able to hear and understand spoken messages in classrooms, the background sound pressure level should not exceed 35 dB equivalent sound level (Leq) during teaching sessions.

The impact assessment should distinguish noise impacts among alternatives, including quantifying the number of sensitive receptors that would be exposed for each alternative. This information may be useful to decision-makers and reveal opportunities to minimize impacts to the most affected receptors during micro-siting of turbines.

Water Resources

Water Supply

The DEIS should estimate the quantity of water the project will require, identify the source of this water, and discuss potential effects of this water use on other water users and natural resources in the project's area of influence. The project would be located over the Cottonwood-Campo sole source aquifer indicating that there may be limited alternatives to groundwater.

Large turbines require substantial foundations and the substantial amount of concrete typically used in these foundations requires a large amount of cement, sand, and aggregate. We understand that a typical 1.5 MW wind turbine can require up to 6,500 gallons of water for each turbine foundation mixture. Additionally, access roads require water for dust control. The DEIS for the East County Substation, Tule Wind and Energia Sierra Juarez Gen-Tie Project estimated that 1.3 million gallons of water would be required for each mile of new access road. The DEIS should indicate the availability of the groundwater supply needed for construction and operation of the proposed project. Discuss the feasibility of using reclaimed water from the Tribe's Acorn Casino. Any potential for subsidence and impacts to springs and biological resources should be evaluated.

Wetlands/Waters of the U.S.

The DEIS should describe all waters of the U.S. (WOUS) that could be affected by the project alternatives and include maps that clearly identify all waters within the project area. The discussion should include acreages and channel lengths, habitat types, values, and functions of these waters, including their relationship to waters downstream. Describe the original (natural) drainage patterns in the project area and identify whether any components of the proposed project are within the 100-year floodplain.

We recommend early coordination with the Army Corps of Engineers to determine if the proposed project requires a Section 404 permit under the Clean Water Act (CWA). If a permit is required, since this project is on tribal land, EPA would be the entity to issue the Clean Water Act Section 401 Water Quality Certification.

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[4] ANSI S12.60-2002 American National Standard, Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools

Regardless of whether a CWA 404 permit is required, because of the valuable hydrologic, biochemical, and geochemical functions of drainages, the project should avoid and minimize direct and indirect impacts to drainages, including erosion, migration of channels, and local scour. We recommend the following:

- Avoid placing turbine support structures in drainages;
- Commit to the use of natural washes, in their present location and natural form and including adequate natural buffers, for flood control to the maximum extent practicable;
- Reconfigure the project layout, roads, and constructed drainage channels to avoid ephemeral washes within the project footprint;
- Minimize the number of roads and road crossings over drainages, and design necessary crossings to provide adequate flow-through during storm events;
- Avoid placing fencing across drainages.

If avoidance will take place during micro-siting, discuss the process of avoidance that will occur.

Stormwater Construction Permit and Groundwater Pollution Prevention
The DEIS should note that, under the Federal Clean Water Act, any construction project disturbing a land area of one or more acres requires a construction storm water discharge permit. Since the project would be on tribal land, EPA would be the issuing agency. See https://www.epa.gov/npdes/epas-2017-construction-general-permit-cgp-and-related-documents for more information on the construction general permit. The DEIS should document the project's consistency with applicable storm water permitting requirements including a storm water pollution prevention plan (SWPPP). Obtaining a permit does not guarantee Best Management Practices (BMPs) will be implemented and effective; however, and BMP effectiveness should be discussed. The primary factor influencing effectiveness is regular inspections and maintenance, including reinstallation or application of the BMP if necessary. The DEIS should identify the parties responsible for implementing the BMPs required by the permit.

The DEIS should note that the Campo/Cottonwood Creek aquifer which underlies the site has been designated as a Sole Source Aquifer (SSA) under Section 1424(e) of the Safe Drinking Water Act. If hazardous materials are used during construction or operation, the DEIS should document appropriate spill control and source water protection measures to prevent soil and groundwater contamination.

We note that the Construction General Permit states that, before submitting a Notice of Intent (NOI) for permit coverage, the operator must ensure and document that discharges are not likely to jeopardize the continued existence of any Federally-listed endangered or threatened species under the Endangered Species Act (ESA). In addition, the operator's SWPPP must contain documentation of permit eligibility regarding the protection of endangered species and critical habitat. Documentation must include: (1) information on whether federally-listed or endangered or threatened species or critical habitat are located near the site; (2) whether such species or habitat may be adversely affected by the stormwater discharges or related activities coming from the site; (3) the results of the screening determination from Appendix C of the permit; and (4) confirmation of delivery of NOI to EPA or to EPA's electronic NOI system.

Air Quality
The DEIS should discuss ambient air conditions (baseline or existing conditions), National Ambient Air Quality Standards (NAAQS), criteria pollutant nonattainment areas, and potential air quality impacts of the proposed project (including cumulative and indirect impacts).

General Conformity

The DEIS should address the applicability of Clean Air Act (CAA) Section 176 and EPA's general conformity regulations at 40 CFR Parts 51 and 93. Federal agencies need to ensure that their actions conform to an approved implementation plan. Mitigation may be available to reduce the project's air emissions, including particulate matter less than 10 and 2.5 microns in diameter (PM10 and PM2.5 respectively), diesel particulate matter (DPM), ozone precursors (oxides of nitrogen (NOx)) and volatile organic compounds.

San Diego County was designated as a non-attainment area for the 2008 ozone standard effective July 20, 2012, with a "Marginal" classification (77 FR 30088). The County was designated nonattainment for the 2015 ozone standard on June 4, 2018 with a "Moderate" classification effective August 3, 2018 (83 FR 25776). These designations, as well as the following changes to the area's classification, specifically include the Indian country of the Campo Indian Reservation.

San Diego County was changed from "Marginal" to "Moderate" nonattainment for the 2008 ozone NAAQS effective June 3, 2016 (81 FR Page 26697). On November 14, 2018, EPA proposed to determine that San Diego County has failed to attain the 2008 ozone NAAQS (83 FR 56781). The effect of a final determination of failure to attain for San Diego County would be a reclassification from "Moderate" to "Serious" nonattainment. As the proposal explains, EPA is obligated by statute to make a final decision on whether the area has attained the 2008 ozone NAAQS within six months of July 20, 2018.

Construction Emissions Mitigation

Because existing conditions do not meet air quality standards, the DEIS should identify mitigation measures that can reduce emissions from project construction and operations and should adopt reasonable mitigation measures as feasible. We recommend the DEIS identify the location of sensitive receptors in the project area (residences, health care facilities, schools, etc.), and locate construction equipment and staging zones away from these receptors. In addition, we recommend the following measures to reduce fugitive dust and vehicle combustion emissions.

Fugitive Dust Controls:

- Phase grading operations where appropriate. Install wind erosion control techniques (such as windbreaks, water, chemical dust suppressants, and/or vegetation) where soils are disturbed in construction, access and maintenance routes, and materials stock pile areas. Keep related windbreaks in place until the soil is stabilized or permanently covered with vegetation. Operate water trucks for stabilization of surfaces under windy conditions.
- When hauling materials and operating non-earthmoving equipment, prevent spillage and limit speeds to 15 miles per hour (mph). Limit speed of earth-moving equipment to 10 mph.
- Provide gravel ramps of at least 20 feet in length at tire washing/cleaning stations and ensure construction vehicles exit construction sites through treated entrance roadways.

Equipment Emissions Mitigation:

- Ensure all construction-related engines: (1) are tuned to the engine manufacturer's specification in accordance with an appropriate time frame; (2) do not idle for more than five minutes (unless, in the case of certain drilling engines, it is necessary for the operating scope); (3) are not tampered with in order to increase engine horsepower; (4) include particulate traps, oxidation catalysts and other suitable control devices on all construction equipment used at the project site; (5) use diesel fuel having a sulfur content of 15 parts per million or less, or other suitable alternative diesel fuel, unless such fuel cannot be reasonably procured in the market area. The determination of which equipment is suitable for control devices can be made by an independent Licensed Mechanical Engineer. Equipment suitable for control devices may include drilling equipment, generators, compressors, graders, bulldozers, and dump trucks.

- The California Resources Board (CARB) has a number of mobile source anti-idling requirements that could be adopted by the Tribe. See http://www.arb.ca.gov/msprog/truck-idling/truck-idling.htm;
- If practicable, lease new, clean equipment meeting the most stringent of applicable Federal standards. In general, commit to the best available emissions control technology.
- Consider using electric vehicles, natural gas, biodiesel, or other alternative fuels during construction and operation phases to reduce the project's criteria and GHG pollutant emissions.
- Plan construction scheduling to minimize vehicle trips.

Biological Resources

Birds and Bats

EPA recommends coordination with the U.S. Fish and Wildlife Service (USFWS) on matters pertaining to species and habitat protection. We offer the following recommendations based on our experience with multiple wind projects.

Construction of the proposed project would involve clearing vegetation and soil disturbance for new access roads, wind turbine foundations, a collector substation, and switchyard and transmission facilities. The DEIS should describe the current quality and capacity of habitat and its use by wildlife in the proposed project area, especially bats and avian populations. The DEIS should identify any impacts the proposed project will have on the species and their habitats; and how the proposed project will meet requirements under the Endangered Species Act, the Migratory Bird Treaty Act (MBTA), and the Bald and Golden Eagle Protection Act (BGEPA).

Wind energy generation projects have the potential to disrupt important wildlife species habitat, resulting in mortality of migratory species such as birds and bats due to collisions with rotors. The DEIS should consider whether migratory birds are likely to use the project area and avoid, if possible: 1) areas supporting a high density of wintering or migratory birds, 2) areas with high level of raptor activity, and 3) breeding, wintering or migrating populations of less abundant species which may be sensitive to increased mortality as a result of collision.

The DEIS should discuss various bird impact reduction strategies and their feasibility, such as: blade-painting schemes that improve visual contrast of wind turbine blades against a terrain or the sky, or color schemes that may reduce motion smear; detect-and-curtail/deter approaches where automated or human detections of target species can result in shutting down wind turbines or activating deterrents such as noise emitters or lights; acoustic or visual deterrents to discourage wildlife from approaching a wind turbine or its rotor; wildlife seasonal curtailment where operation is curtailed during one or more seasons of the year to eliminate fatalities; and turbine design features that minimize potential attraction, perching, or deterring or alerting wildlife to the hazard (via noise and/or lights).

The DEIS should discuss expected bat mortality rates. The Campo Shuluuk Wind Project DEIS noted that most bat fatalities have been recorded in the Fall, coinciding with peaks in echolocation activity, and that bat species are at most risk during August and September because juveniles are flying and fall migration is occurring. Low wind speeds have been correlated with increased bat fatalities. The DEIS should discuss bat monitoring and whether it's possible to turn off turbines during some of these conditions to minimize bat mortality. If alternatives vary in terms of the size of the turbines, the DEIS should discuss any information available regarding differences in pressure change for various turbine sizes that could affect barotrauma and other impacts on bats.

In 2012, the USFWS published a set of guidelines and recommendations on how to avoid and minimize impacts of land-based wind farms on wildlife and habitat (Land-Based Wind Energy Guidelines, available https://www.fws.gov/ecological-services/es-library/pdfs/WEG_final.pdf). We recommend that BIA and the Tribe consult these guidelines and incorporate them into project planning.

Transmission Lines

The NOI indicates that A new 230 kV overhead generation transmission line would be constructed, on the Campo Indian Reservation and partially outside on private lands, from the project collector substation on the Reservation to a San Diego Gas & Electric (SDG&E) substation/switchyard that would be constructed on private lands adjacent to the Sunrise Powerlink northeast of the Reservation. Transmission lines may have a visual impact and pose a potential collision and electrocution hazard for birds, especially when located in a migratory corridor. These impacts should be assessed and if potentially significant, lines should be moved to avoid impacts, as feasible.

We recommend consulting the Avian Power Line Interaction Committee's publication *Reducing Avian Collisions With Power Lines: The State of the Art in 2012* (sample copy available: https://www.aplic.org/uploads/files/11218/Reducing_Avian_Collisions_2012watermarkLR.pdf) so that recommended practices can be incorporated into the project. We recommend mitigation measures be included to restore landscapes that are temporarily disturbed at the conductor stringing and tensioning sites, as well as any temporary construction and material laydown areas.

Invasive Species

Executive Order 13112, Invasive Species (February 3, 1999), mandates that federal agencies take actions to prevent the introduction of invasive species, provide for their control, and minimize the economic, ecological, and human health impacts that invasive species cause. Executive Order 13112 also calls for the restoration of native plants and tree species. The DEIS should address this issue since the new access roads have the potential to introduce invasive species into new areas. The DEIS should describe how the project will meet the requirements of Executive Order 13112. We recommend that the project include development of an invasive plant management plan to monitor and control noxious weeds.

Hazards

Wind turbines can malfunction and cause explosions, which can lead to wildfires. The DEIS should discuss this and any other hazards that could occur and identify what measures are available to prevent such hazards as well as the resources that are available to respond to them.

Cumulative Impacts

The cumulative impacts analysis should identify how resources, ecosystems, and human communities of concern have already been affected by past or present activities in the project area. Characterize these resources in terms of their response to change and capacity to withstand stresses. Trends data should be used to establish a baseline for the affected resources, to evaluate the significance of historical degradation, and to predict the environmental effects of the project components.

For the cumulative impacts assessment, we recommend focusing on resources of concern or resources that are "at risk" and/or are significantly impacted by the proposed project, before mitigation. For this project, BIA and the Tribe should ensure that a thorough assessment of the cumulative impacts to bird and bat species is included, especially in the context of the larger wind power developments in the area. Additionally, air quality is currently not meeting air quality standards for ozone and thus would be cumulatively impacted by the proposed project.

EPA assisted in the preparation of a guidance document for assessing cumulative impacts and we recommend consideration of its use for the DEIS. While this guidance was prepared for transportation projects in California, the principles and the 8-step process outlined therein can be applied to other types of projects and offers a systematic way to analyze cumulative impacts for a project. The guidance is available at: http://www.dot.ca.gov/ser/cumulative_guidance/purpose.htm.

Environmental Justice

Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations (February 11, 1994), directs federal agencies to identify and address disproportionately high and adverse human health or environmental effects on minority and low-income populations, allowing those populations a meaningful opportunity to participate in the decision-making process. The DEIS should describe measures taken by BIA to: (1) fully analyze the environmental effects of the proposed actions on minority and low-income populations, both within the tribe and in affected areas not on tribal land; and (2) present opportunities for affected communities to participate in the NEPA process, including information and participation materials in all languages spoken by those in affected areas. Assessment of the projects' impact on minority and low-income populations should reflect coordination with those affected populations.

Visual Impacts

Careful attention should be given to how a wind turbine array is set against the landscape. Steps should be taken, if possible, to minimize the visual impacts and make the wind turbines less obtrusive. When evaluating the visual impacts attempt to assess what degree they may affect the important visual resources in the surrounding area. Discuss the impact of shadow flicker on health and well-being.

Valley Fever

The project site is located in an area that the Centers for Disease Control[5] has classified a "suspected endemic" for Coccidioides immitis, a fungus causing Valley Fever. Ground disturbing activities associated with the proposed action may result in dispersal of Coccidioides spores. Discuss this potential health and safety impact in the DEIS and identify measures to prevent or reduce the risk of exposure to workers and residents.

[5] https://www.cdc.gov/fungal/diseases/coccidioidomycosis/maps.html#approximate

We appreciate the opportunity to provide scoping comments for this project and are available to discuss our comments. When the DEIS is available for public review, please send one electronic copy to the address above (mail code: ENF-4-2). If you have any questions, please contact me at (415) 947-4178 or vitulano.karen@epa.gov.

Sincerely,

Karen Vitulano
Environmental Review Section

cc: Dan (Harold) Hall, Acting Chief, Division of Environmental, Cultural Resource Management and Safety, Bureau of Indian Affairs
Ralph Goff, Chairman, Campo Band of Mission Indians
Lisa Gover, Environmental Director, Campo Band of Mission Indians

Backcountry Against Dumps

PO Box 1275, Boulevard, CA 91905

December 20, 2018

TO: Dan (Harold) Hall, Acting Chief Division of Environmental, Cultural Resource Management and Safety, Bureau of Indian Affairs, via harold.hall@bia.gov ; Bronwyn Brown, San Diego County PDS via: Bronwyn.brown@sdcounty.ca.gov ; CC elected officials

FROM: Donna Tisdale, as Backcountry Against Dumps (BAD) President, and as an individual; 619-766-4170; tisdale.donna@gmail.com

RE: CAMPO WIND EIS SCOPING COMMENTS; REQUEST FOR 30-45 DAY COMMENT EXTENSION AND NEW SCOPING MEETING & JOINT NEPA/CEQA EIS/EIR REVIEW OF CAMPO WIND, TORREY WIND AND BOULDER BRUSH GEN-TIE.

Our Group is a 501(c) 4 public benefit non-profit (DBA Backcountry Against Dumps) whose main purpose is to defend rural communities and resources from unsafe facilities and projects. Our Board of Directors has unanimously authorized the submission of these comments in opposition to Campo Wind. These comments are in addition to those that will be filed by the Law Offices of Stephan C. Volker on our behalf by the December 21st comment deadline.

Terra-Gen's Campo Wind, Torrey Wind, and Boulder Brush Gen-Tie line are being piecemealed AS separate projects. Together, they represent one large project and must be reviewed with a joint NEPA/CEQA EIS/EIR. Separately and combined, they represent a major threat to our community's public health, safety, and overall well being.

We hereby incorporate by reference the Campo Wind EIS Scoping comments submitted by the Boulevard Planning Group, dated December 20, 2018.

Regards,

Donna Tisdale, President

BOULEVARD PLANNING GROUP

PO BOX 1272, BOULEVARD, CA 91905

DATE: December 20, 2018

TO: Dan (Harold) Hall, Acting Chief Division of Environmental, Cultural Resource Management and Safety, Bureau of Indian Affairs, via harold.hall@bia.gov; Bronwyn Brown, San Diego County PDS via: Bronwyn.brown@sdcounty.ca.gov ; CC elected officials

FROM: Boulevard Planning Group (BPG) and Donna Tisdale as BPG Chair, and an individual; 619-766-4170; tisdale.donna@gmail.com

RE: CAMPO WIND EIS SCOPING COMMENTS; REQUEST FOR 30-45 DAY COMMENT EXTENSION & NEW SCOPING MEETING; JOINT CEQA/NEPA REVIEW IS REQUIRED OF TERRA-GEN'S CONNECTED ACTION/WHOLE OF THE PROJECT CAMPO WIND, TORREY WIND & BOULDER BRUSH GEN-TIE PROJECTS—IT IS ONE PROJECT NOT THREE!

The Boulevard Planning Group is an elected land use advisory group under the jurisdiction of San Diego County. At our monthly meeting, held one day early on Wednesday December 5th to accommodate the December 6th Scoping Meeting, our Group voted to authorize submission of these scoping comments in opposition to Terra-Gen's Campo Wind project proposed for the Campo Reservation.

We have repeatedly heard from members of our impacted at-risk community who have been adversely impacted by the existing Kumeyaay Wind turbines on the Campo Reservation and the Tule Wind turbines located on public BLM land and private land within BLM boundaries. Both projects have generated complaints to our group regarding noise, vibrations, visual, electrical and light pollution, sleep deprivation, adverse health impacts, loss of the use and enjoyment of their homes and properties, cell phone interference, impacts to wildlife and livestock, poor maintenance of turbines, fires, shadow-flicker, catastrophic failures, blade shedding, and more. We have also heard from residents impacted by Energia Sierra Juarez Wind turbines near Jacumba and Ocotillo Wind turbines east of McCain Valley. Their complaints are consistent with other turbine-impacted residents around the globe.

Our Group is aware of previous professional noise and electrical pollution testing that documented the presence of infrasound, low-frequency noise, and electromagnetic interference at the homes near the Kumeyaay Wind and Ocotillo Wind turbines where measurements were conducted. More recent professional noise /infrasound testing was arranged by Backcountry Against Dumps and is being compiled into a report that will be provided at the next public comment opportunity.

TORREY WIND MUP COMMENTS ARE INCORPORATED BY REFERENCE:

- Because we know that Torrey Wind, Campo Wind, and Boulder Brush Gen-tie are one large connected action/whole of the project, not three separate projects. We hereby incorporate in full by reference our 26-page comment letter submitted on July 22, 2018 to Bronwyn Brown the Project Manager for San Diego County. Some information may be repetitive. (Copy attached)

ALLEDGEDLY ILLEGAL GENERAL COUNCIL VOTE SOULD NULLIFY THE LEASE AGREEMENT:

- There is tribal opposition to the project. Even with limited public notice and a heavy rain storm, two tribal members stood up and spoke out at the Scoping Meeting in opposition to Campo Wind. Going against tribal leadership can be very risky with potential for repercussions.
- Tribal members have informed us privately, and stated publicly at the Scoping Meeting, that the General Council vote taken in April 2018, to enter into the Wind Lease Agreement with Terra-Gen Development LLC, was illegal and should be null and void.
- Campo's General Council meeting in April 2018 was reportedly noticed as an information only meeting on the lease. No vote was supposed to be taken.
- Campo's General Counsel Resolution 04-03-2018-01 Terra-Gen Wind Lease Agreement, April 3, 2018 includes the following at the top of page 2:
    - "Now Therefore, the General Council, in a specially called and duly noticed meeting, at the date set forth above, after discussion and the opportunity to review the Wind Lease Agreement, upon motion duly made and seconded, hereby resolves as follows…"
- However, allegations have been made that Chairman Goff and/or other tribal leaders excused the General Council members from the "information only" meeting and failed to inform them that a vote would be taken with the remaining project supporters once the others had left the building, thereby violating their civil rights under the US Constitution and the American Indian Civil Rights Act of 1968
    - General Council Members have the right to be fully and timely informed and to vote on leases involving their land as required by law and the Campo Band's constitution.
    - No Indian Tribe can legally deny General Council members the right to equal protection under the law.
    - No Indian Tribe can legally take any property/homes for a public use, such as commercial energy generation, without just compensation.
    - Both tribal and adjacent private homes and families are at risk and may potentially be impacted by wind turbine-generated noise, EMI, and related stress to the point they may need to abandon their homes to preserve their health. For tribal members, with limited housing stock, this would be especially harsh with limited options for safely remaining on their turbine-infested tribal lands.

REQUEST FOR EXTENDED/ADDITIONAL 30-45 DAY COMMENT PERIOD & NEW SCOPING MEETING

- This formal request is made due to inadequate Notice of Intent, Scoping Meeting notice, the inadequate Scoping Meeting itself, and lack of critical information materials made available to the public in a timely manner, including members of the Campo Band, prior to the December 21st scoping comment deadline.
- Most people did not know about this project or the important scoping meeting due to inadequate notice to tribal members and the impacted off-reservation community.
- Terra-Gen Development Company, LLC was not identified as the Campo Wind developer.

- In fact, no developer was identified in the Notice of Intent (Federal Register 11-21-18)[1] or Scoping Meeting notice (posted 11-21-18)[2] which limits and hinders the scope of public comment**.**
- Failure to provide copies of any project map and potential turbine and other infrastructure locations and setbacks from homes, roads, and other occupied structures, prior to scoping meeting or to post it on www.campowind.com, in a timely manner before close of scoping on December 21, 2018.
- Promises were made at the scoping meeting by Matt Valerio of Dudek that he would post a better copy of the sole vague map that was shown only in the power point presentation and that he would also post the entire presentation at www.campowind.com .
- As of the comment deadline, neither the promised map nor the meeting presentation has been posted.
- Speakers were limited to just 3 minutes each at Scoping Meeting when only 10 speakers actually made public comments. A few more were signed up but decided not to speak.
- Mr. Dan (Harold) Hall seemed impatient and unreceptive to public comment opposing the project. At one point, he admonished one speaker to be respectful when the speaker had not been disrespectful.
- People repeatedly asked for maps and more detailed information that was not provided.
- Mr. Hall announced the shut-down of the meeting at 6:50 PM when the Notice of Intent and Scoping Meeting notice specifically advertised that the meeting would be held between 6-9PM.

IS CAMPO WIND THE REGISTERED LEGAL NAME OF THE PROJECT?

- The NOI and Scoping Notice and project website identify the project as follows: Campo Wind Energy Project; Campo Wind Project; Campo Wind.
- However, on the California Secretary of State's site for registered business entities[3], there is no Campo Wind Energy Project, Campo Wind Project, or Campo Wind listed as either a LP/LLC or as a Corporation. The only other way to look up a company name is to have the ID number.
- Is there another name for this project? Is it registered with the Secretary of State?
- Terra-Gen's Torrey Wind was called San Diego Wind during initial review until around April 27, 2018 when Terra-Gen registered Torrey Wind LLC[4] (18-C34232) with the Secretary of state.
- Terra-Gen apparently held off registering Torrey Wind LLC with the State until they got the Wind Lease Agreement approved with the Campo Band in April, 2018, that would expand Torrey Wind to include Campo Wind for their single 400MW CAISO interconnection application #1429.

CONNECTED ACTION/WHOLE OF THE PROJECT REQUIRES JOINT NEPA/CEQA REVIEW. TERRA-GEN AND DECISION MAKERS ARE CURRENTLY AND UNETHICALLY ATTEMPTING TO PIECEMEAL ONE LARGE PROJECT INTO THREE SEPARATE PROJECTS. THE OVERALL CUMULATIVELY SIGNIFICANT ASVERSE IMPACTS OF TERRA-GEN'S ENTIRE LARGE PROJECT, ALONG WITH EXISTING AND PROPOSED PROJECTS,

[1] http://dudek.com/campowind/CampoWind_NOI.pdf
[2] http://dudek.com/campowind/CampoWind_Public%20Scoping%20Meeting%20Notice.pdf
[3] https://businesssearch.sos.ca.gov/
[4] https://businesssearch.sos.ca.gov/Document/RetrievePDF?Id=201812810321-24174691

ON OUR DISPROPORTIONATELY IMPACTED AND PREDOMINANTLY LOW-INCOME COMMUNITY AT LARGE MUST BE FULLY DISCLOSED AND ANALYZED IN A JOINT EIS/EIR.

- Failure of the Notice of Intent to identify and include Terra-Gen's connected action/whole of the project wind turbine project named Torrey Wind that is planned for adjacent private land with a Major Use Permit (PDS2018-MUP-18-014) currently under review by San Diego County.
- Also under a current Major Use Permit review by the County is Terra-Gen's connected action/whole of the project Boulder Brush Gen-Tie line project that will connect Campo Wind to the same substation switchyard that is currently proposed as part of the Torrey Wind project.
- Both Campo Wind and Torrey Wind will use the same Torrey Wind substation/switchyard to connect to the grid via SDG&E's Sunrise Powerlink located on the Torrey Wind project site.
- The Campo Wind NOI and Scoping notice incorrectly indentify the proposed Campo Wind switchyard/substation as belonging to SDG&E[5] when it is in fact Terra-Gen's proposed infrastructure that is intended to be transferred to SDG&E at some point in the future.
- Terra-Gen representatives, including Ken Wagner, have directly confirmed to Donna Tisdale and others that both Campo Wind and Torrey Wind will use the same single CAISO grid connection queue # 1429 for 400MW (C10)[6]. The interconnection request was received on 4/27/17.
- Terra-Gen also confirmed that they would be using the same 4 + MW turbines for both their 126 MW Torrey Wind and their 252 MW Campo Wind, without identifying what brand and model of turbine—something that needs to be disclosed so we can research noise impacts from that make and model.
- Together, Torrey Wind and Campo Wind equal 378 MW, just under Terra-Gen's 400 MW grid queue application.
- Is there a proposed expansion of Campo Wind/Torrey Wind planned for the adjacent Manzanita and/or La Posta Indian Reservations that would use the remaining 22 MW, approximately 5-4.2MW turbines? Terra-Gen reps said no, but we have learned from experience not to trust developers' statements and denials as factual.
- SDG&E's previous Manzanita Wind project was proposed at 27 MW. They attempted to auction the project off in 2014[7].
- More recently, Manzanita tribal members have stated that their leadership has authorized 5-7 wind turbines for their reservation land, allegedly using similar questionable votes.
- Disclosure of Terra-Gen's new Boulder Brush LLC gen-tie line and related wind turbines on the Campo Reservation, referenced in the gen-tie project description, are connected actions/projects and require a joint CEQA/NEPA EIR/EIS review of all direct, indirect, and cumulative impacts of the larger interconnected project overall along with those of existing, approved, and reasonably foreseeable proposed industrial wind, solar, and related utility lines, substations, switchyards, roads, water use, and more.
- The National Environmental Policy Act (NEPA) requires joint review of connected projects.
- The Citizen's Guide to NEPA[8]. See Section 1508.25 Scope at page 46 of the pdf:

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[5] See NOI at page 3: http://www.campowind.com/
[6] See #1429 @ page 1501 of the CAISO grid queue: https://rimspub.caiso.com/rims5/logon.do#
[7] https://www.sdge.com/sdge-auction-manzanita-wind-project
[8] https://ceq.doe.gov/docs/get-involved/Citizens_Guide_Dec07.pdf

    - This section describes Connected Actions, Cumulative Actions and Similar Actions that represent connected projects (Campo Wind, Boulder Brush LLC gen-tie and Torrey Wind), independent parts of a larger action (Campo Wind &Torrey Wind) and depend on the larger action (Torrey Wind's substation/switchyard connection to Sunrise Powerlink, etc.) for their justification, basically a 'but for" situation.
- The Boulder Brush gen-tie and related Campo Wind turbines would not proceed '*but for'* Torrey Wind and Torrey Wind substation/switchyard. They are all connected and must be analyzed in a joint CEQA/NEPA EIR/EIS.

CAMPO WIND TURBINES JUST ADD INSULT TO INJURY FROM EXITING TURBINES - WHO OWNS THE EXISTING KUMEYAAY WIND TURBINES?

- Numerous attempts, research, and outreach to the Campo leadership, the Regional Director of BIA, other BIA officials, various business entities, and the California Public Utilities Commission staff have failed to identify the current owner of the Kumeyaay Wind turbines and the party liable for nuisance, pain, and suffering already caused since those 25 Gamesa G87 turbines that started operation in late 2005.
- Information posted on the Campo Nation website regarding Kumeyaay Wind[9] is apparently outdated. It lists Enxco but clicking on the link takes you to EDF Renewables.
- Calls and emails to EDF Renewables have gone nowhere. Claims have been made that they are no longer involved with Kumeyaay Wind.
- So, who is in charge and liable for nuisance claims?
- Where can and should legitimate complaints be filed?
- Even the CPUC staff has not been able to provide current ownership/management information.

Kumeyaay Wind suffered a catastrophic failure in December 2009 that resulted in a major shutdown and litigation to replace all 75 blades and electronic components:

- **Gamesa | January 2010 Highlights: Extreme wind analysis**[10]:
    - The Kumeyaay Wind farm, located 60 miles east of San Diego on the Campo Indian Reservation, is a 50MW, 25 turbine wind site producing enough power for 32,500 homes.
    - On December 7, 2009 the Kumeyaay Wind Project experienced an extreme wind which caused catastrophic damage to many of the wind turbine blades. 23 of the 25 turbine were deemed inoperable. Due to the extensive damage, the blades on all the turbines were replaced. Gamesa engaged AWS Truepower to conduct an analysis of the extreme wind event. The analysis was made more difficult by the fact that no SCADA data was available during the event due to a power outage. AWS Truepower bridged this gap using wind data from a nearby tower. The information helped AWS Truepower delineate the climatic conditions at each turbine in order to determine if the conditions exceeded the International Electrotechnical Commission (IEC) design specifications.

[9] http://www.campo-nsn.gov/windfarm.html
[10] https://aws-dewi.ul.com/about-us/case-study/kumeyaay-wind-project-extreme-wind-analysis-san-diego-california/

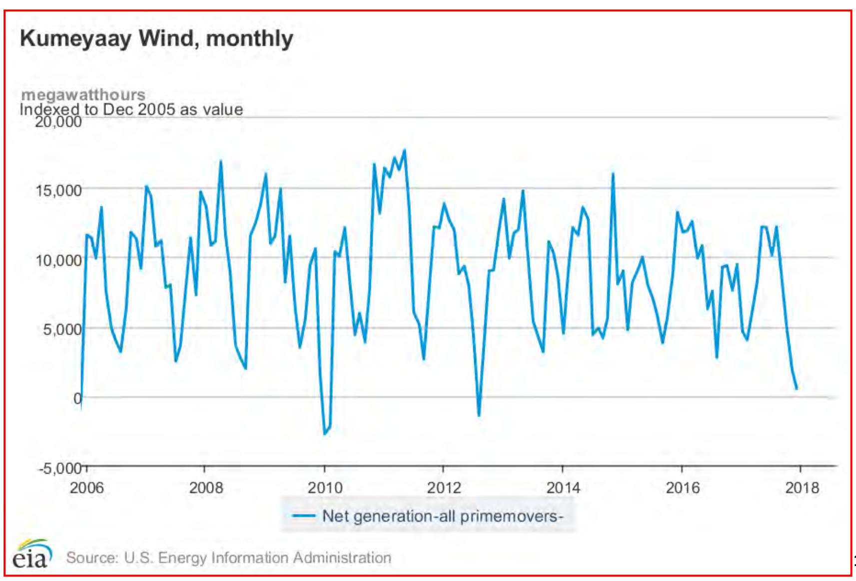
- Each blade was removed from every turbine at this wind farm.
- A 10-minute wind speed and turbulence intensity record for each turbine was presented by AWS Truepower. The analysis concluded that in fact the IEC design specifications were exceeded for turbulence, although the maximum wind speed threshold was not exceeded.

- **Infigen And Gamesa End Years-Long Legal Battle Over Wind Turbines Posted by North American Wind Power, June 17, 2013[11]:**
  - Australia-based Infigen Energy, which has interests in 18 U.S. wind farms, and Gamesa Wind US LLC announced that they have settled all outstanding legal proceedings related to Gamesa-manufactured turbines purchased by Infigen.

  - The long-lasting legal disputes related to five U.S. wind farms in which Infigen holds interest, particularly California's Kumeyaay Wind Farm. Following a December 2009 storm, Infigen claimed Gamesa was liable to pay over $30 million for site repairs and replacement of all 75 wind turbines at Kumeyaay. Gamesa, meanwhile, maintained that Kumeyaay Wind LLC should bear the costs.

THE CAPACITY FACTOR AT THE EXISTING KUMEYAAY WIND, TULE WIND, OCOTILLO WIND, AND ENERGIA SIERRA JUAREZ WIND ARE PROVIDED BELOW TO PROVIDE A REAL WORLD FACT-BASED LOOK AT WHAT LOCAL WIND PROJECTS PRODUCE ANNUALLY. TOGETHER, THEIR AVERAGE GENERATION/CAPACITY IS 28.07%. THAT MEANS THEY DID NOT PRODUCE ENERGY ALMOST 72% OF THE TIME!

- **Kumeyaay Wind : Generation/Capacity factor per year 2006-17: 25-2MW Gamesa wind turbines = 50MW/hr x 24hr/day x 365 days/year = 438,000 MW annual maximum: Average production over 12 years = 32.15% (translates into 67.85% lack of production)**



[12]

[11] https://nawindpower.com/infigen-and-gamesa-end-years-long-legal-battle-over-wind-turbines

- 2006: 137,983 = 31.50%
- 2007: 148,009 = 33.70%
- 2008: 152,733 = 34.87%
- 2009: 143,354 = 32.72%
- 2010: 121,456 = 27.73%
- 2011: 176,303 = 40.25%
- 2012: 134,281 = 30.66%
- 2013: 148,277 = 38.85%
- 2014: 139,936 = 31.95%
- 2015: 126,691 = 28.92%
- 2016: 142,816 = 32.61%
- 2017: 118,478 = 27.05%

- Kumeyaay Wind annual production rate figures were sourced from EIA on 11/24/18; Electric data browser: Kumeyaay Wind Plant Code: 56295[13]

Tule Wind - Generation/Capacity Factor per Month
TULE WIND - 2018 GENERATION/CAPACITY FACTOR per MONTH January-September = average of 26.31 %

Month	Days	# Turbines	Max Capacity	Max MWH's	Actual MWH's	Capacity Factor
Jan	31	57/2.3 MW	132 MW per hr.	98208	22332	22.73%
Feb	28	57/2.3 MW	132 MW per hr.	88704	32410	36.53%
Mar	31	57/2.3 MW	132 MW per hr.	98208	41903	42.66%
Apr	30	57/2.3 MW	132 MW per hr.	95040	13155	13.94%
May	31	57/2.3 MW	132 MW per hr.	98208	14137	14.38%
Jun	30	57/2.3 MW	132 MW per hr.	95040	37259	39.20%
Jul	31	57/2.3 MW	132 MW per hr.	98208	15097	15.37%
Aug	31	57/2.3 MW	132 MW per hr.	98208	20578	20.95%
Sep	30	57/2.3 MW	132 MW per hr.	95040	29573	31.11%
Oct	31	57/2.3 MW	132 MW per	98208		

[12] https://www.eia.gov/electricity/data/browser/#/plant/56295?freq=M&start=200512&end=201808&chartindexed=2&ctype=linechart&ltype=pin&pin=&maptype=0&linechart=ELEC.PLANT.GEN.56295-ALL-ALL.M~ELEC.PLANT.GEN.56295-WND-ALL.M~ELEC.PLANT.GEN.56295-WND-WT.M&columnchart=ELEC.PLANT.GEN.56295-ALL-ALL.M

[13] www.eia.gov/electricity/data/browser/#/plant/56295

			hr.			
Nov	30	57/2.3 MW	132 MW per hr.	95040		
Dec	31	57/2.3 MW	132 MW per hr.	98208		

Energy Information Administration information on Tule Wind was only available thru Sept 2018, as of Dec 21st comment deadline
https://www.eia.gov/electricity/data/browser/#/plant/57913/?freq=M&pin=

Energia Sierra Juarez Wind (ESJ) production:

- ESJ Wind started production on 3/27/15.
- With 155.1 MW, the maximum for ESJ would be 1,358,676 MWh per year—if turbines operated 24.7 which they don't.
- According to the California Energy Commission website's power plant statistical data for the 155.1 MW ESJ Wind project (Plant #W0460) [14] :
  - 2016 production was 422,821 MWh = 31.12%
  - 2017 production was 443,382 MWh = 32.62%
- The 2-year average = 31.87%

Ocotillo Wind (Express) Capacity Factor Spread Sheet

	2013	2014	2015	2016	2017	2018	2019	2020
January	9.29%	6.76%	1.11%	14.86%	22.27%	8.23%		
February	19.43%	21.10%	13.77%	12.17%	20.41%	16.00%		
March	29.87%	26.19%	14.81%	33.93%	25.16%	26.25%		
April	35.02%	34.02%	36.46%	36.91%	34.46%	42.41%		
May	16.74%	43.87%	44.56%	43.81%	34.93%	52.37%		
June	0.00%	46.34%	30.86%	29.66%	30.10%	38.86%		
July	0.00%	30.95%	34.25%	34.94%	20.62%	21.55%		
August	14.65%	26.78%	26.76%	16.70%	24.43%	31.80%		
September	18.28%	19.87%	20.12%	23.09%	27.44%	20.98%		
October	15.64%	11.79%	17.29%	22.52%	20.61%			
November	14.83%	18.10%	15.21%	6.12%	13.62%			
December	13.06%	6.81%	21.62%	3.45%	3.76%			
Average	***15.96%***	***20.17%***	***21.13%***	***21.64%***	***23.15%***			

Average Ocotillo Wind Capacity Factor thru 2017 = 21.95%

[14] https://www.energy.ca.gov/almanac/electricity_data/web_qfer/plant_stats_2.php

ONE THING TO KEEP IN PERSPECTIVE IS THAT THE EXISTING WIND TURBINE PROJECTS REPORTEDLY DEVELOPED THE BEST LOCAL WIND RESOURCE AREAS. THAT MEANS THAT TERRA-GEN'S COMBINED CAMPO WIND AND TORREY WIND WILL LIKELY HAVE A LOWER CAPACTIY FACTOR, THEREBY GENERATING LESS ENERGY AND INCOME. THERE WILL ALSO BE WAKE EFFECTS FROM EXISTING TURBINES THAT WILL IMPACT PRODUCTION FOR ALL LOCAL TURBINES, BOTH NEW AND EXISTING. WHEN SUPERIOR ENERGY WAS DEVELOPING KUMEYAAY WIND, THEY INFORMED DONNA TISDALE DIRECTLY THAT THE SOUTHERN END OF THE CAMPO RESERVATION WAS NOT AN OPTIMUM SITE FOR TURBINES.

<u>NOISE AND ADVERSE HEALTH IMPACTS:</u>

On the graphic above, please note the size of the person standing next to the turbine base, highlighted in the yellow circle. Please remember that Terra-Gen's Campo Wind and Torrey Wind turbines are expected *to be 4.2 MW and 586 feet tall—some of the largest onshore turbines! Unlike tall stationary high-rise buildings, these turbines rotate, twist, groan, whine, roar, vibrate, generate electrical pollution, shadow flicker that can extend thousands of feet , throw blades, ignite, explode, shed flaming debris, create a visual blight, adverse health effects, impact wildlife , livestock and pets, destroy property values and quality of life, create both a public and private nuisance and more…*

- What turbine setbacks will be allowed by the Campo Band, the BIA, the Department of Interior and San Diego County?
- Current San Diego County setback limits are vastly inadequate to protect public health and safety, including potential blade throw and tower collapse for these monster turbines.
- **October 2018: World Health Organization (WHO) releases new noise guidelines with new sources including wind turbines[15]:**
  - **What is new:** Compared to previous WHO guidelines on noise, this version contains five significant developments (emphasis added):
    - stronger evidence of the cardiovascular and metabolic effects of environmental noise;
    - ***inclusion of new noise sources, namely wind turbine noise and leisure noise, in addition to noise from transportation (aircraft, rail and road traffic);***
    - use of a standardized approach to assess the evidence;
    - ***a systematic review of evidence, defining the relationship between noise exposure and risk of adverse health outcomes***;
    - use of long-term average noise exposure indicators to better predict adverse health outcomes.
  - "***These guidelines have been developed based on the growing body of evidence in the field of environmental noise research****," concludes Professor Stephen Stansfeld, Chair of the Guidelines Development Group. "They aim to support public health policy that will protect communities from the adverse effects of noise, as well as stimulate further research into the health effects of different types of noise."*
- **September 11, 2018: Turbine bombshell: Noise 'detrimental and unreasonable'; South Gippsland Sentinel Times; Australia[16](Excerpts-emphasis added)**
  - A new investigation into Bald Hills Wind Farm noise complaints has found that neighbours' health concerns are legitimate. m173718
  - THE investigation commissioned by the South Gippsland Shire Council, at a cost of $33,600, into Noise Complaint Notifications by residents living near the Bald Hills Wind Farm is complete. And two and a half years after they first made their grievances known, the report has found their complaints were fully justified. Described by the shire as "a highly experienced independent public health consultant", at his appointment in February this year, James C. Smith and Associates has found that "there is a nuisance caused by wind farm noise, in that, the noise is audible frequently within individual residences and this noise is adversely impacting on the personal comfort and wellbeing of individuals".

[15] http://www.euro.who.int/en/media-centre/sections/press-releases/2018/press-information-note-on-the-launch-of-the-who-environmental-noise-guidelines-for-the-european-region
[16] http://sgst.com.au/2018/09/turbine-bombshell/

- The investigation by James C. Smith and Associates has found:
  "That there is a consistency with the information contained in the completed log books and with subsequent discussions held with Mr Zakula, Mr and Mrs Fairbrother, Mr and Mrs Jelbart, and Mr Uren about their individual experiences with wind farm noise during that period. "Without exception there are allegations that the wind farm noise is audible inside their individual homes and, as a result, there is sleep disruption during the night and early morning hours. There are also allegations that the wind farm noise is disruptive to day-time domestic and work activities.

- **May 1, 2018: Harvard Medical School: Understanding the stress response: *Chronic activation of this survival mechanism impairs health*[17]. *(Excerpts-emphasis added)***

  - *"A stressful situation — whether something environmental, such as a looming work deadline, or psychological, such as persistent worry about losing a job — can trigger a cascade of stress hormones that produce well-orchestrated physiological changes. A stressful incident can make the heart pound and breathing quicken. Muscles tense and beads of sweat appear."*

  - *"This combination of reactions to stress is also known as the "fight-or-flight" response because it evolved as a survival mechanism, enabling people and other mammals to react quickly to life-threatening situations. The carefully orchestrated yet near-instantaneous sequence of hormonal changes and physiological responses helps someone to fight the threat off or flee to safety. Unfortunately, the body can also overreact to stressors that are not life-threatening, such as traffic jams, work pressure, and family difficulties".*

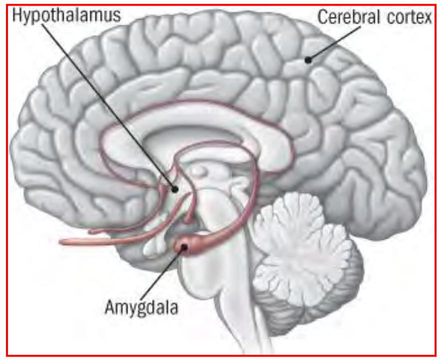
  - *"Over the years, researchers have learned not only how and why these reactions occur, but have also gained insight into the long-term effects chronic stress has on physical and psychological health. Over time, repeated activation of the stress response takes a toll on the body. Research suggests that chronic stress contributes to high blood pressure, promotes the formation of artery-clogging deposits, and causes brain changes that may contribute to anxiety, depression, and addiction. More preliminary research suggests that chronic stress may also contribute to obesity, both through direct mechanisms (causing people to eat more) or indirectly (decreasing sleep and exercise)."*

    - *Sounding the alarm*

      - *"The stress response begins in the brain (see illustration). When someone confronts an oncoming car or other danger, the eyes or ears (or both) send the information to the amygdala, an area of the brain that contributes to emotional processing. The amygdala interprets the images and sounds. When it perceives danger, it instantly sends a distress signal to the hypothalamus."*

[17] https://www.health.harvard.edu/staying-healthy/understanding-the-stress-response

- *"Command center"*



Note- according to impacted residents, wind turbines can generate the stress response fight or flight syndrome. It can become chronic, depending on length of exposure to infrasound and low-frequency noise (ILFN), electromagnetic pollution / EMI and other impacts.

- **February 5, 2018; Science Daily: American College of Cardiology. TRAFFIC NOISE-INDUCED HARM TO CARDIOVASCULAR SYSTEM[18]: (emphasis added) *Summary:***
  - "*Noise may disrupt the body on the cellular level in a way that increases the risk of common heart disease risk factors, according to a new review that examined the underlying mechanisms that may lead to noise-induced heart disease. The review is in response to growing evidence connecting environmental noise, including from road traffic and aircrafts, to the development of heart disease, such as coronary artery disease, arterial hypertension, stroke and heart failure*".
  - Note: noise from wind turbines is environmental noise that cannot be ignored!
- **Wind Turbine Noise and Human Health : A four-Decade History of Evidence that Wind Turbines Pose Risks by Punch & James; revised 10-21-2015: 72 pages with 180 citations**[19]:
  - Their conclusion at pages 52-55 states (emphasis added): "*We have discussed in this paper various elements of acoustics, sound perception, sound measurement, and psychological reactions, and the role these factors play in support of the view that a general-causative link exists between human health and ILFN emitted by IWTs. The available evidence warrants the following conclusions*:"
  - 12 conclusions are listed and available in the full document linked below.
- The wind industry has generally and disingenuously stated that those property owners who have a financial stake in a wind project don't complain. However, some participating property owners in other areas have been subjected to contractual gag orders that prevent them from complaining while others have testified that "the noise was unbearable:
- **June 10, 2015 Farmers Testimony: 'The noise was unbearable'[20]: (Excerpt-emphasis added)**

[18] https://www.sciencedaily.com/releases/2018/02/180205141116.htm

[19] https://hearinghealthmatters.org/journalresearchposters/files/2016/09/16-10-21-Wind-Turbine-Noise-PostPublication-Manuscript-HHTM-Punch-James.pdf

[20] http://www.windaction.org/posts/42907-farmers-testimony-the-noise-was-unbearable#.W5Vi8-hKiUk

- "*Clive and Petrina Gare presented their story before the Australian Senate Select Committee on Wind Turbines. The Gares leased their land to a wind developer for 19 turbines to be erected. The nearest turbine was sited about 800 metres away from their home with three towers within approximately one to 1.5 kilometres away. In total, they were paid $200,000 per year for hosting the machines. The construction phase was difficult but when the turbines were placed in service in October 2010, the situation became unbearable. The Gares, and others, gave testimony before the Australian Senate Select Committee on Wind Turbines*."
    - The full testimony available in the link provided.

- **46-page 2015 report: Infrasound Low Frequency Noise and Industrial Wind Turbines: prepared for the Multi-Municipal Wind Turbine Working Group[21]**:
    - Report Conclusion (emphasis added): "*Based on information presented here, infrasound generated by wind turbines must be considered a potential direct cause of adverse health reactions widely reported from wind turbine host communities. Now that so many indicators point to infrasound as a potential agent of adverse health effects, it is critical to re-examine the approach to this aspect of wind turbine operation, revise regulations, and immediately implement protective public health measures based on the precautionary principle*,"

- **May 1, 2010: Sleep Duration and All-Cause Mortality: A Systematic Review and Meta-Analysis of Prospective Studies: Cappuccio FP; D'Elia L; Strazzullo P; Miller MA. Sleep duration and all-cause mortality: a systematic review and meta-analysis of prospective studies. *SLEEP* 2010;33(5): 585-592**.(Sleep Research Society)[22]
    - <u>Conclusion:</u> Both short and long duration of sleep are significant predictors of death in prospective population studies.

- **2007 Southern Medical Journal: Noise Pollution: A Modern Plague by Lisa Goines, RN, and Louis Hagler, MD[23]:** This article lists 7 known adverse health effects recognized by WHO at the time. The text from number 3, that includes low-frequency noise impacts, is cut and pasted below (citations in #3 are found in the full 2007 article linked below):
    - ***"3. Sleep Disturbances:*** *Uninterrupted sleep is known to be a prerequisite for good physiologic and mental functioning in healthy individuals.[28] Environmental noise is one of the major causes of disturbed sleep.[1, 10] When sleep disruption becomes chronic, the results are mood changes, decrements in performance, and other long-term effects on health and well-being.[3] Much recent research has focused on noise from aircraft, roadways, and trains. It is known, for example, that continuous noise in excess of 30 dB disturbs sleep. For intermittent noise, the probability of being awakened increases with the number of noise events per night.[1]*
    - *The primary sleep disturbances are difficulty falling asleep, frequent awakenings, waking too early, and alterations in sleep stages and depth, especially a reduction in REM sleep. Apart from various effects on sleep itself, noise during sleep causes increased*

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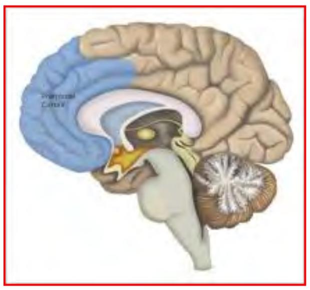
[21] http://www.windvigilance.com/about-adverse-health-effects/low-frequency-noise-infrasound-and-windturbines
[22] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2864873/
[23] See linked full article for embedded reference links: http://www.yourownhealthandfitness.org/Documents/Hagler_Noise_pollution.pdf

blood pressure, increased heart rate, increased pulse amplitude, vasoconstriction, changes in respiration, cardiac arrhythmias, and increased body movement.[28] *For each of these, the threshold and response relationships may be different. Some of these effects (waking, for example) diminish with repeated exposure; others, particularly cardiovascular responses, do not.*[29] *Secondary effects (so-called after effects) measured the following day include fatigue, depressed mood and well-being, and decreased performance.*[30] *Decreased alertness and disrupted circadian rhythms, which lead to accidents, injuries, and death, have also been attributed to lack of sleep.*[31]

- *Long-term psychosocial effects have been related to nocturnal noise. Noise annoyance during the night increases total noise annoyance for the following 24 hours. Particularly sensitive groups include the elderly, shift workers, persons vulnerable to physical or mental disorders, and those with sleep disorders.*[1]
- *Other factors that influence the problem of night-time noise include its occurrence in residential areas with low background noise levels and combinations of noise and vibration such as produced by trains or heavy trucks. Low frequency sound is more disturbing, even at very low sound pressure levels; these low frequency components appear to have a significant detrimental effect on health.*[32] *"*

- **Division of Sleep Medicine at Harvard Medical: Sleep and Disease Risk, December 2007[24]:** This piece lists the connections between sleep deprivation and the following: increased stress; obesity; diabetes; heart disease and hypertension; mood disorders; immune function; alcohol use; lower life expectancy. **(Excerpts with emphasis added)**
  - *The Relationship Between Sleep and Health Not getting enough sleep can have profound consequences on a daily and potentially long-term basis for your health and mental well-being.*
  - *We all have some sense of the relationship between sleep and our ability to function throughout the day. After all, everyone has experienced the fatigue, bad mood, or lack of focus that so often follow a night of poor sleep. What many people do not realize is that a lack of sleep—especially on a regular basis—is associated with long-term health consequences, including chronic medical conditions like diabetes, high blood pressure, and heart disease, and that these conditions may lead to a shortened life expectancy. Additional research studies show that habitually sleeping more than nine hours is also associated with poor health.*
  - *Researching the Link Between Sleep Duration and Chronic Disease. There are three main types of study that help us understand the links between sleep habits and the risk of developing certain diseases. The first type (called sleep deprivation studies) involves depriving healthy research volunteers of sleep and examining any short-term physiological changes that could trigger disease. Such studies have revealed a variety of potentially harmful effects of sleep deprivation usually associated with increased stress, such as increased blood pressure, impaired control of blood glucose, and increased inflammation.*

[24] http://healthysleep.med.harvard.edu/healthy/matters/consequences/sleep-and-disease-risk

- **Division of Sleep Medicine at Harvard Medical: Sleep, Performance, and Public Safety, December 2007[25]:** This piece addresses the connections between sleep deprivation and loss of cognitive functions, judgment, and increased risk. (Excerpt emphasis added)
  - *"In addition to the feeling of sleepiness and changes in brain activity that accompany a night without sleep, other measures of performance are noticeably altered. Concentration, working memory, mathematical capacity, and logical reasoning are all aspects of cognitive function compromised by sleep deprivation. However, not all of these functions rely on the same regions of the brain, nor are they impacted by sleep deprivation to the same degree. For example, the region of the brain known as the prefrontal cortex (PFC) is responsible for many higher-level cognitive functions and is particularly vulnerable to a lack of sleep. As a result, people who are sleep deprived will begin to show deficits in many tasks that require logical reasoning or complex thought."*
  - ***"The prefrontal cortex is responsible for many higher-level cognitive functions and is particularly vulnerable to a lack of sleep".***

- **The Effects of Sleep Deprivation on Your Body posted on healthline.com[26]:**
  - The body's impacted systems include:
    - Central Nervous System
    - Immune System
    - Respiratory System
    - Digestive System
    - Cardiovascular System
    - Endocrine System
  - The infographic posted on healtline.com (link below) lists 11 health effects from sleep deprivation:
    - Memory issues
    - Mood changes
    - Weakened immunity
    - Risk for diabetes
    - Low sex-drive
    - Trouble with thinking and concentration
    - Accidents

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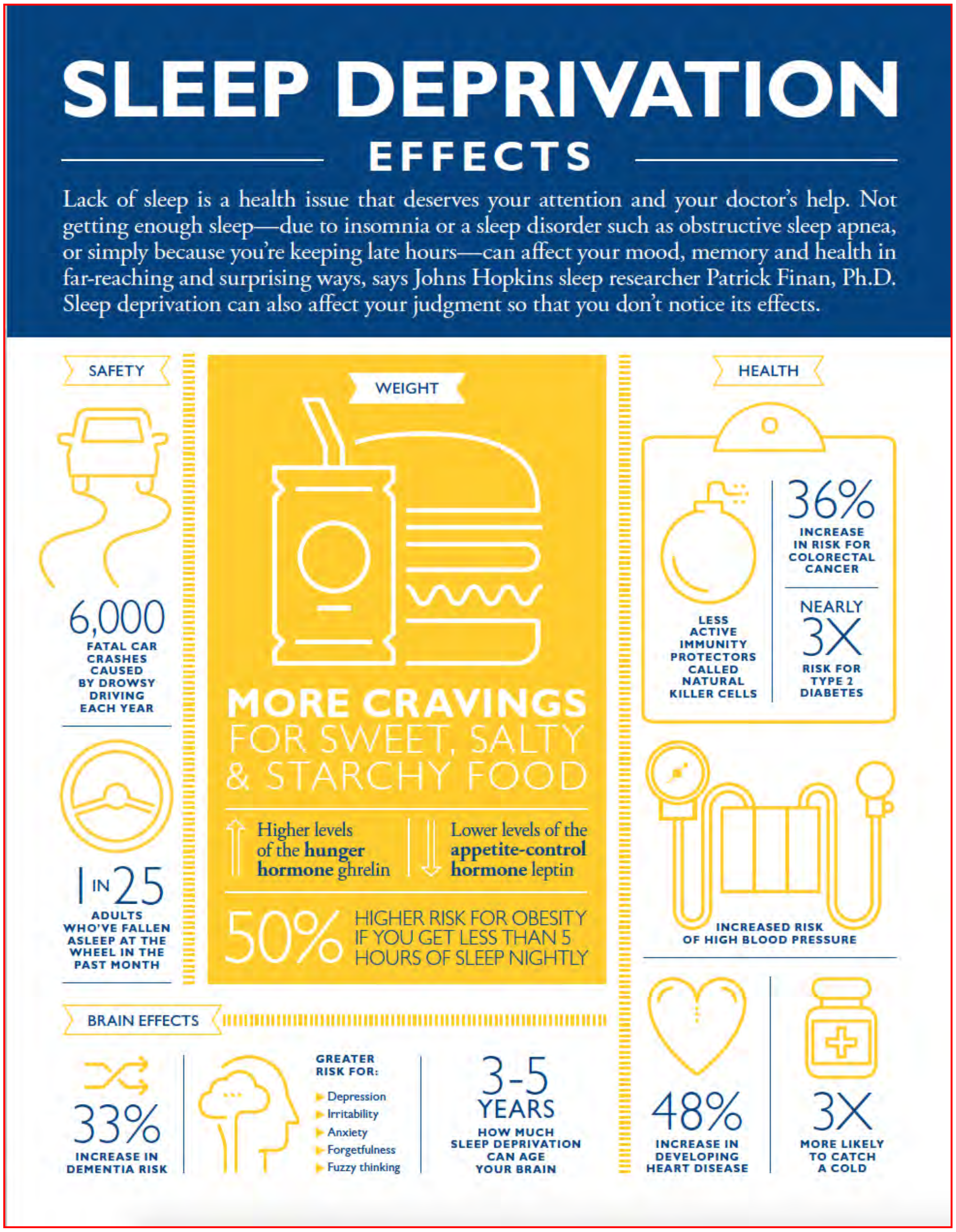
[25] http://healthysleep.med.harvard.edu/healthy/matters/consequences/sleep-performance-and-public-safety
https://www.healthline.com/health/sleep-deprivation/effects-on-body#1
[26] https://www.healthline.com/health/sleep-deprivation/effects-on-body#2

- High blood pressure
- Weight gain
- Risk of heart disease
- Poor balance

John Hopkins Medicine: The Effects of Sleep Deprivation

- Not getting enough sleep can affect your mood, memory and health in far-reaching and surprising ways, says Johns Hopkins sleep researcher Patrick Finan, Ph.D. [27] See sleep deprivation infographic copied below:



[27] https://www.hopkinsmedicine.org/health/healthy-sleep/health-risks/the-effects-of-sleep-deprivation

AIR QUALITY ANALYSIS MUST INCLUDE ELECTRICAL / EMI, NOISE / ILFN POLLUTION:

- Electromagnetic pollution electromagnetic interference (EMI) generated by industrial wind turbines and other project components radiates off the project site through the air, the ground, and induction into adjacent homes and properties via electrical and grounding lines, plumbing, and ground current.
- In general, Electromagnetic Fields (EMFs) present concerns in addition to those from possible direct influences of fields on tissues and organs of the body. These include potential health risks from induced currents, electric shock, effects on cardiac pacemakers, and nuisance factors.
- **EMFs and effects of induced currents on the human body is explained as follows**[28]:
  - *"Within the body, currents induced by fields have the same range of effects as currents injected via electrodes, e.g. in an electric shock. But these effects depend entirely on the size of the current. Thus current densities of about 0.1 A m-2 can stimulate excitable tissue and current densities above about 1 A m-2 can cause ventricular fibrillation, as well as producing heating. However these current densities correspond to fields far larger than are ever encountered at 50 Hz."*
  - *"At lower fields a range of possible effects have been reported. The established effect observed in humans at the lowest magnetic field is the magnetophosphene effect, where a flickering sensation is produced in peripheral vision by 50 Hz magnetic fields above about 10 mT (i.e. 10,000 µT). Magnetophosphenes are probably caused by induced current densities in the retina; the threshold at 20 Hz (the most sensitive frequency) is about 20 mA m-2."*
  - *These concerns must be fully recognized, analyzed, and addressed in the EIR/EIS.*
  - *These groupings of independent electrical generators generate extreme low frequency (ELF) electromagnetic field radiation, power quality issues (voltage variations, frequency transients, harmonics, wiring and grounding issues).*
  - *They can be considered as high wattage ELF electromagnetic broadcast - transmitter towers and due to their high current output create strong alternating magnetic fields. Although their radiation efficiency may be low they are still sources-notwithstanding the possible inadvertent induced coupling into the connected grid and thousands of miles of its transmission lines which might make for a more efficient antenna.*
  - *Electric and magnetic fields / radiation are vector fields and need to be properly analyzed and addressed in the EIS/EIR.*
- **A press release from University of North Carolina, Chapel Hill News Service (Largest study finds evidence of association between EMFs and exposed worker suicide-March 15, 2000-#147)[29] includes the following excerpts(emphasis added):**
  - *A report on the study, which began with a group of 138,905 male U.S. electric utility workers, appears today (March 15) in the April issue of Occupational and Environmental Medicine. Authors include doctoral student Edwin van Wijngaarden; Dr. David A. Savitz, professor and chair of epidemiology; Dr. Jianwen Cai, associate professor of biostatistics; and Dr. Dana Loomis, associate professor of epidemiology, all at the UNCCH School of*

[28] http://theproblemwithwindpower.com/info/inductionfield.jpg

[29] http://www.unc.edu/news/archives/mar00/savitz2031500.htm

Public Health. Statistical programmer Dr. Robert C. Kleckner also contributed to the project.

- *Extreme low frequency (ELF) has been associated with reduced melatonin, depression and suicide. Why low frequency electromagnetic fields might contribute to suicide among chronically exposed workers is not known, van Wijngaarden said.*
- *"One biologically plausible explanation is that EMFs depress production of melatonin, a hormone that's important for sleep and mood," he said. "Decreases in melatonin can lead to depression, which in turn can lead to suicide."*

- **Previous testing was conducted at homes impacted by the Kumeyaay and Ocotillo Wind turbines and is being submitted here:**
  - The field studies performed by professional experts document the presence of electrical and low-frequency noise pollution at homes where residents have complained of EMI, noise, sleep disruption, anxiety, and numerous adverse health impacts including cancer.
  - East County Magazine article summarized several local studies conducted at homes impacted by the Kumeyaay and Ocotillo Wind turbines, and embedded the documents with clickable links: http://www.eastcountymagazine.org/print/12714
  - Environmental Assay Inc conducted an assessment of power quality and EMF exposure at Campo and Manzanita homes near the Kumeyaay Wind Turbines and residents near the Ocotillo Wind turbines in Imperial County (2-2013)[30].
  - Comment Letter on Shu'luuk Wind project (previously proposed for Campo Reservation) from Dr. Samuel Milham to the Bureau of Indian Affairs (1-19-13) documenting electrical pollution he found at impacted homes[31].
  - Comment letter on Shu'luuk Wind to Bureau of Indian Affairs from Richard James, INCE, E-Coustic Solutions (2-25-13)[32]. Based on his professional experience and research related to industrial wind turbines , low-frequency noise ,infrasound, including homes abandoned after turbines started operation near them, he recommends turbines be located no closer than 1.25 miles from homes.

WIND TURBINE IMPACTS ON COMMUNICATIONS / CELL PHONE, INTERNET & MORE

- **Impact analysis of wind farms on telecommunication services; D.de la Vega[a]I.Cascón[a]J.Cañizo[a]Y.Wu[b]D.Guerra[a]P.Angueira[a] [33]; renewable and Sustainable Energy**

[30]Report:https://www.eastcountymagazine.org/sites/eastcountymagazine.org/files/2013/March/Manzanita%20WT%20Report%20-%20Body%202-24-13C.pdf ; Appendix: https://www.eastcountymagazine.org/sites/eastcountymagazine.org/files/2013/March/Manzanita%20WT%20Report%20Appendices%20B%2CC%2CD%20Rev%202-14-13.pdf

[31]http://www.eastcountymagazine.org/sites/eastcountymagazine.org/files/2013/March/Shuluuk%20DEIS%20Dr%20S%20Milham%201-19-13.pdf

[32] https://www.eastcountymagazine.org/sites/eastcountymagazine.org/files/2013/March/Shuluuk%20DEIS%20Rick%20James%202-25-13.pdf

[33] https://doi.org/10.1016/j.rser.2013.12.055

Reviews, Volume 32, April 2014, Pages 84-99 (EXCERPT-this study was completed with the help of Iberdrola the Tule Wind developer)

- *"Wind power is one of the fastest-growing technologies for renewable energy generation. Unfortunately, in the recent years some cases of degradation on certain telecommunication systems have arisen due to the presence of wind farms, and expensive and technically complex corrective measurements have been needed. This paper presents a comprehensive review on the impact of wind turbines on the telecommunication services. The paper describes the potential affections to several telecommunication services, the methodology to evaluate this impact, and mitigation measures to be taken in case of potential degradation, both preventive and corrective…"*

FAILURE TO PROVIDE SAFE HOUSING

- The existing Kumeyaay Wind turbines are generating noise and electrical pollution and related adverse sleep deprivation and other serious stress-related health impacts.
- There have been numerous stomach and kidney aliments and cancers, upper respiratory, and health issues reported at tribal homes impacted by Kumeyaay Wind turbines. Tribal offices are also impacted with some Manzanita tribal members impacted at work and at home.
- Sleep deprivation and stress-related illnesses have also been reported at off-reservation homes impacted by Kumeyaay Wind turbines with exacerbated conditions commencing with the late 2017 operation of Iberdrola/Avangrid's Tule Wind turbines.
- **At HUD.Gov, it states the following (emphasis added) "*The role of the Office of Public and Indian Housing is to ensure safe, decent, and affordable housing*…"**
- **The Indian Health Service, Division of Environmental Health Services (DEHS)** is one of several partners responsible for ensuring environmentally-healthy homes to a population of over 2 million American Indians and Alaska Natives[34].
- **The DEHS Mission:** *"Through shared decision making and sound public health measures, enhance the health and quality of life of all American Indians and Alaska Natives to the highest level by eliminating environmentally related disease and injury"*.[35]
- ***The Campo Band's Housing Department also has direct responsibilities and liabilities related to providing environmentally safe and sustainable housing***:
  - By placing 60 or so 586-foot tall 4+ MW industrial wind turbines and other infrastructure far too close to homes, tribal offices and facilities, education center, health clinic, and business operations represents a form of inverse condemnation or taking of tribal member's homes/land without just compensation and creating unsafe working environments for members and non-tribal employees.
  - Again, some tribal members will be impacted at home, at work, and /or at school.
  - Turbines generate noise, low frequency noise, infrasound, and electrical and light pollution that trespass into homes and properties thereby creating a public and private nuisance and adversely impacting the use and enjoyment of that property and the related quality of life. The same is true for private homes impacted off the reservation.

[34] https://www.ihs.gov/dehs/includes/themes/responsive2017/display_objects/documents/priorities/Healthy%20Homes.pdf

[35] https://www.ihs.gov/dehs/

    - New tribal and private off-reservation housing will be limited by the addition of up to 60 industrial 4+MW wind turbines and necessary setbacks, thereby preventing additional much needed housing options.
    - Some homes and other occupied structures may be deemed toxic due to increased noise, infrasound, vibrations, and electromagnetic interference that can generate a host of stress-related symptoms, illnesses, and exacerbated existing conditions.
    - At the Scoping Meeting, a tribal member identified herself as Michelle Cuero and a project opponent. She stated that the Campo Band is working on enrolling up to 100 new members. Where will they live if turbine placement impacts housing location and safety?
    - Some existing homes may be abandoned if deemed unsafe to occupy. Homeowners around the globe have abandoned their homes due to turbine generated suffering.
- ***Dr Riina I. Bray BAsc, MSc, MD, FCFP, MHSc Medical Director, Environmental Health Clinic, Women's College Hospital Assistant Professor, Department of Family and Community Medicine, University of Toronto Cross-Appointment Dalla Lana School of Public Health- warns of proximity to industrial wind turbines (excerpts-read full letter and citations at link provided)*** [36]:
    - *"I am writing to express concern about the potential for harm for human health represented by Ontario's Industrial Wind Turbines (IWTs) and their supporting infrastructure."*
    - *"Research has demonstrated how various forms of pollutant from IWTs can adversely affect human health. These include noise, infra-sound, dirty electricity, and ground current which can each, along with shadow flicker, contribute to ill-health among those who live near wind turbines".*

NEPA ENVIRONMENTAL JUSTICE REQUIREMENTS[37]:

- In light of Executive Order 12898, the White House Council on Environmental Quality (CEQ) issued Environmental Justice; Guidance Under the National Environmental Policy Act (December, 1997) (PDF)(40 pp, 2.3 MB). This guidance includes six principles for environmental justice analyses to determine any disproportionately high and adverse human health or environmental effects to low-income, minority, and tribal populations. The principles are:

    1. Consider the composition of the affected area to determine whether low-income, minority or tribal populations are present and whether there may be disproportionately high and adverse human health or environmental effects on these populations
    2. Consider relevant public health and industry data concerning the potential for multiple exposures or cumulative exposure to human health or environmental hazards in the affected population, as well as historical patterns of exposure to environmental hazards
    3. Recognize the interrelated cultural, social, occupational, historical, or economic factors that may amplify the natural and physical environmental effects of the proposed action
    4. Develop effective public participation strategies

[36] http://greatlakeswindtruth.org/featured/just-in-dr-riina-bray-of-womens-college-hospital-warns-of-proximity-to-wind-turbines/
[37] https://www.epa.gov/environmentaljustice/environmental-justice-and-national-environmental-policy-act

5. Assure meaningful community representation in the process, beginning at the earliest possible time
6. Seek tribal representation in the process

- **How will the BIA and other co-operating agencies handle this NEPA EJ obligation? Judging by the poor handling of the December 6th Scoping Meeting and inadequate notice and information made available to the public, major concerns are justified**.

CEQA's ENVIRONMENTAL JUSTICE:

- ***Former Attorney General Kamala Harris's referenced 2012 6-page Fact Sheet on Environmental Justice at the local and regional level is incorporated in full by reference***[38].
- The Torrey Wind project and Boulder Brush gen-tie line projects are believed to be located in and predominantly impact the Mt. Empire Census Tract 211, Block Group 3 that has previously been identified as having high poverty classification.
- Boulder Brush LLC wind turbines proposed for the Campo Reservation will likely include Census Tract 211 Block Group 3 and Block Group 2. Block Group 2 has previously been identified as having a high minority percentage.
- These same census blocks have suffered disproportionate and considerably cumulative adverse impacts from existing proposed, approved, and reasonably foreseeable energy and utility projects that represent various forms of pollution and other hazards that can lead to negative public health effects, exposure to noise and electrical pollution, and environmental degradation overall.
- **Health and Safety Code Section 39711 states that disadvantaged communities may include, but are not limited to, either of the following**:
  - (1) Areas disproportionately affected by environmental pollution and other hazards that can lead to negative public health effects, exposure, or environmental degradation. o (2) Areas with concentrations of people that are of low income, high unemployment, low levels of homeownership, high rent burden, sensitive populations, or low levels of educational attainment.

OUR CALIFORNIA CONSTITUTIONAL RIGHTS [39] AND SIMILAR RIGHTS UNDER THE US CONSTITUTION MUST BE DEFENDED AND PROTECTED:

- California Article 1 Section 1: All people are by nature free and independent and have inalienable rights. Among these are enjoying and defending life and liberty, acquiring, possessing, and protecting property, and pursuing and obtaining safety, happiness, and privacy.
- California Article 1 section 7: A person may not be deprived of life, liberty, or property without due process of law or denied equal protection of the laws…
- California Article 1 section: Cruel or unusual punishment may not be inflicted or excessive fines imposed[40].

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[38] https://oag.ca.gov/sites/all/files/agweb/pdfs/environment/ej_fact_sheet_final_050712.pdf

[39] https://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=CONS&division=&title=&part=&chapte r=&article=I

- Inverse condemnation of property
- Subjection to noise and /or electrical pollution can be considered cruel and unusual punishment of sorts and people are allowed by right to protect and defend themselves, their families, and their properties from these unsafe projects that threaten public health and safety and well being.

SUNRISE POWERLINK CAPACITY IS REPORTED AS 1,200-1,300 MW[41]. IS CAPACITY AVAILABLE FOR CAMPO WIND AND TORREY WIND?

- **June 30, 2015 joint letter from the California Energy Commission (CEC) and the California Public Utilities Commission (CPUC) to the California Independent Systems Operator (CAISO) stated that the Sunrise Powerlink had a capacity of 1,300 MW and was at capacity and that one year after initial energization it was fully utilized with wind solar and geothermal from the east**.
- Sunrise Powerlink was also reported at capacity in article on Wistaria Ranch Solar project[42] (emphasis added):
    - "*Sunrise Powerlink is already at full capacity, Kelley said, and there are no more Power Purchase Agreements being issued right now. Therefore, the energy generated would have nowhere to move at this time*".
    - The Imperial County Board of Supervisors approved a 10 year conditional use permit for Wistaria Solar due to lack of transmission capacity to connect the project to the grid.
    - What is the current available capacity on Sunrise Powerlink? Does that include the other local pending energy projects like Rugged Solar, Boulevard Solar, solar proposed on Empire Ranch on Jewel Valley Road, and any others?
    - What is the real Sunrise capacity? When the number of projects are added up, that have publicly claimed to be connected to Sunrise Powerlink, via media or planning documents, it adds up to over 2,000MW.
    - Terra-Gen's single CAISO grid connection queue number for Campo Wind, Boulder Brush Gen-Tie, and Torrey Wind is 1429 for 400MW.

SOCIO ECONOMIC ISSUES SHOULD INCLUDE PROPERTY VALUES. ADVERSE IMPACTS MUST BE ANALYSED RELATED TO DIMINISHED PRICE (UP TO 60%), INCREASED MARKETING TIME, AND DECREASED SALES VOLUMES. TERRA-GEN SHOULD BE REQUIRED TO OFFER PROPERTY VALUE GUARANTEE AGREEMENTS FOR CAMPO WIND, TORREY WIND, AND BOULDER BRUSH GEN-TIE:

- Maps should be prepared and provided in the joint DEIS/EIR that show just how many homes will be within at least a 2-5 mile radius/impact zone of both Campo Wind and Torrey Wind turbines.

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[40] http://www.windvigilance.com/about-adverse-health-effects/low-frequency-noise-infrasound-and-windturbines
[41] DRECP appendix K @page 1 footnote 4: https://www.drecp.org/draftdrecp/
[42] https://oag.ca.gov/sites/all/files/agweb/pdfs/environment/ej_fact_sheet_final_050712.pdf
5https://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=CONS&division=&title=&part=&chapt e r=&article=I

- Turbines are too big (586 ft tall) and too close to homes and property lines. They will dominate, industrialize and degrade /destroy currently quiet scenic rural landscapes, ambiance, amenity, and the quality of life that goes with them.
- ***Adverse Impacts to property values require Property Value Protection Agreements. The courts have required some wind project developers to compensate buy-out and/ or destroy impacted homes that were bought-out to avoid damages to another resident.***
    - Turbines represent increased fire risk and related insurance costs.
    - Noise, light and electrical (electromagnetic interference-EMI) pollution require legitimate Health Impact Assessments be conducted for those who are already suffering from wind turbines being authorized and constructed far too close for public health and safety.
    - Public – taxpayer funds pay millions of dollars for wind turbine tax credits, investment credits, renewable energy credits, reduced property taxes, and other financial incentives for multi-billion dollar Terra-Gen developer.
    - Disproportionate adverse impacts from multiple industrial projects to our predominantly low-income rural communities must be fully recognized and analyzed.
    - In addition, overuse of groundwater resources for project construction can adversely impact domestic wells and springs at tribal homes and adjacent private homes, thereby generating potentially great expense to drill new deeper wells-if water can even be located in our drought plagued high-desert area.
    - **Blasting for placement of turbines can cause damage to wells and springs in our highly fractured bedrock aquifer.**
    - The Campo tribal leadership previously authorized bulk water sales for SDG&E's ECO Substation project construction but had to curtail those sales early due to dropped water levels, reduced recharge, and off-site impacts to homes reliant on wells and springs.
    - Contrary to the misinformation efforts of wind developers and their enablers, there is a sizeable amount of evidence that Industrial Wind Facilities negatively impact property values. A compilation of information is readily available upon research.
- **September 2013 report "Southern Tablelands Impact of Wind Farm Development on Surrounding Rural Land Values", by Peter Reardon, Real Estate Consultant and Registered Valuer, based in NSW, Australia[43] includes the summary excerpt copied below that reflects a 33-60% drop in the market place that cannot be ignored**:
    - *"Our current research and findings indicate that this market evidence is now beginning to become available in the Southern Tablelands. Upon analysis, these sales detail a detriment in market value for properties located adjoining or within nearby distance of wind turbine infrastructure. The report has identified a detriment in property values. Discounts in value as identified of 33% & 60% in the market place cannot be ignored."*

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[43] See pages 2-3 @: http://windturbinepropertyloss.org/site/pdf/Southern_Tablelands__Impact_of_Wind_Farm_Development_on_Surrounding_Rural_Land_Values_2013.pdf

- *"As part of our research we have also undertaken extensive communication and surveys with real estate agencies in the Southern Tablelands. The vast majority of all real estate agencies surveyed believed that the location and proximity of wind turbines can have a significant impact upon the marketability of rural land holdings especially in the form of buyer interest and extended sales periods being required. This impact alone is not something that we believe has been accurately measured neither in past studies nor by the proponents of most Wind Farm Developments."*
- *"The detrimental impact upon adjoining and/or nearby land holders appears to be beginning to be acknowledged by a number of wind turbine proponents. A notable example of this is developers in the Boorowa/ Rugby region. Enquiries have detailed that compensation deals are being offered to adjoining and nearby land holders who have a residence within 2 kilometres of wind turbines. The deals being negotiated and signed up to at this current point in time are typically $2,500 p.a. per turbine within a 2 kilometre radius of a residence, indexed for the life of the development in a similar type of agreement to those land holders that are compensated for hosting turbines on their land. "*

- **October 4, 2013: Board of Civil Authority[44]Vermont Grievance Decision Notification in favor of Scott & Melodie McLane, 1179 Georgia Mountain Road, Fairfax, VT: Turbine noise reduces residential property value**
  - The committee felt there was a noise factor to the property caused by the Georgia Wind Project and decided to use the scale (8% to 15% of value) of impact provided by the Assessor based upon the noise level. The committee recommended the property assessed value by the town be reduced by 12%.
- **Appraised before appeal: $409,900; Appraisal after appeal: $360,712: July 22, 2012 article in the DailyMail.com[45]: Wind farms DO hit house prices: Government agency finally admits that thousands can be wiped off value of homes By GERRI PEEV FOR THE DAILY MAIL reports that (Excerpt-emphasis added):**
  - "*The Valuation Office Agency has been forced to re-band homes into lower council tax categories, confirming what most residents who live near the giant turbines already know: they are detrimental to property prices… In one case, a couple saw the value of their home near the Fullabrook wind farm site near Braunton, Devon, fall from £400,000 to £300,000 when they asked estate agents to value it*."
- **Sowers v. Forest Hills Subdivision, 129 Nev. Adv. Op. 9 (Feb. 14, 2013)[46] (Excerpt-emphasis added):**
  - ***UNLV Summary:*** *The Court concluded that (1) the district court's decision to permanently enjoin the wind turbine from being constructed was not clearly erroneous and was supported by substantial evidence, and (2) the district court was correct to*

[44] http://www.windaction.org/posts/38768-vermont-grievance-decision-turbine-noise-reduces-residentialproperty-value#.W5VjBOhKiUk

[45] https://www.dailymail.co.uk/news/article-2177429/Wind-farms-DO-hit-house-prices-Government-agencyfinally-admits-thousands-wiped-value-homes.html#ixzz29ffTJiJO

[46] https://scholars.law.unlv.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=1120&context=nvscs

consider noise, diminution of property value, the presence of a shadow flicker, and the size of the turbine when deciding if the wind turbine constituted a nuisance.

- **Heintzelman, Martin D. & Tuttle, Carrie M."Values in the Wind: A Hedonic Analysis of Wind Power Facilities."** ***Land Economics*****, vol. 88 no. 3, 2012, pp. 571-588.** ***Project MUSE***[47] ***(Excerpt- emphasis added)***
    - ***Abstract***: *"The siting of wind facilities is extremely controversial. This paper uses data on 11,331 property transactions over nine years in northern New York State to explore the effects of new wind facilities on property values. We use a fixed-effects framework to control for omitted variables and endogeneity biases. We find that nearby wind facilities significantly reduce property values in two of the three counties studied. These results indicate that existing compensation to local homeowners/communities may not be sufficient to prevent a loss of property values*."

- **Wind turbines: more residents cite nuisances** ***Credit:*** **Property devaluation, cell phone and Internet interference | By Lindsey Harrison | The New Falcon Herald | Volume No. 13, Issue No. 2 | February 2016**[48] **(excerpt)**

    - When J.T. bought his property in Calhan 16 years ago, he considered it a permanent move. In 2013, J.T. had his property appraised, so he could refinance it. The house appraised for $235,000, he said. The house today is appraised at $194,000, with no viable reasons for the decrease, except for one: the wind farm.

    - The Golden West Wind Farm Project began full operations in October 2015, and J.T. had issues with the project from its inception.

    - "I have a bunch of turbines across the street now," J.T. said. "They totally ruined my panoramic view of the mountains."

    - Additionally, J.T. said the "whoosh" noise from the turbines keep him awake at night, and he has bouts of being disoriented. "I was out driving, and I could not get oriented enough to figure out how to get home," he said.

    - Those issues prompted J.T. to get another appraisal to possibly sell his house and move out of the direct line of the wind farm. "The house was appraised at $194,000," he said. "I have upgraded my house, but there is nothing for sale to compare it to. No one is trying to sell their house now because everyone already sold it for whatever they could before the wind farm came."

    - J.T. said there is no way he could sell his house now, especially at such a depressed value, because no one wants to move close to the wind farm.

- **July 22,2018: An Opinion piece by Ann Wilson**[49]**from Henry County Indiana alleges the following regarding Industrial Wind Turbines** (IWT) (emphasis added):

[47] https://muse.jhu.edu/article/480790/pdf
[48] https://www.wind-watch.org/news/2016/02/06/wind-turbines-more-residents-cite-nuisances/

- *"…What has happened in Jay County since their project became operational? Real estate appraisers advertised to Jay County residents within TEN miles of each turbine to consider having their house and land reappraised, offering assistance with the appraisal and tax appeal process to the Assessor. Horrified, non-lease signers had no idea of the IWT impact, now realizing their trusted county officials have willingly subjected them to diminished values on their greatest investment: their homes. They began sharing experiences of jet engine noise, red blinking lights at night, compromised cell phone & TV reception, and sleep deprivation. Health complaints have grown, along with anger toward their county officials…"*

REMOVAL OF OAK TREES AND OTHER ADVERSE IMPACTS TO SENSITIVE AREAS AND SPEICES MUST BE ADDRESSED – INCLUDING EXISTING, PROPOSED, AND REASONABLY FORESEEABLE WIND, SOLAR AND ELECTRICAL INFRASTRUCTURE PROJECTS THAT IMPACT THE BOULEVARD AND RESERVATION COMMUNITIES, HABITATS, AND MIGRATION CORRIDORS, AT LARGE.

- **Removal of mature oak trees along Church Road and BIA 10 to accommodate the transport of massive wind turbine parts should be avoided at all costs**. It is our understanding that the removal process may be imminent. Removal is especially unwarranted during current extended drought, beetle infestations, and significant oak mortality. Too many local trees and the habitat they represent have already been lost! Where and when will oaks be replaced and what size will they be?
- **Wind farms are the 'new apex predators': Blades kill off 75% of buzzards, hawks and kites that live nearby,** By HARRY PETTIT FOR MAILONLINE , Nov 5, 2018, updated Nov 14,2018[50]:
  - **study shows:**
    - Predatory bird numbers are four times higher in areas away from wins turbines
    - This is having a devastating 'ripple effect' across the food chain
    - It means numbers of certain small animals are growing unchecked
  - Wind turbines are the world's new 'apex predators', wiping out buzzards, hawks and other carnivorous birds at the top of the food chain, say scientists.
  - Researchers at the Indian Institute of Science in Bengaluru studied lizard and bird populations at three wind turbine sites in the Western Ghats.
  - They found almost four times fewer buzzards, hawks and kites in areas with wind farms - a loss of about 75 per cent.
  - In areas without turbines around 19 birds were spotted every three hours, while nearer to the machines this number dropped to around five.

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[49] http://www.windaction.org/posts/48479-tale-of-two-counties#.W5VhmuhKiUk
[50] https://www.dailymail.co.uk/sciencetech/article-6354843/Wind-farms-new-apex-predators-kill-three-QUARTERS-predatory-birds.html?utm_source=CCNet+Newsletter&utm_campaign=c344d7be5b-EMAIL_CAMPAIGN_2018_11_06_04_41&utm_medium=email&utm_term=0_fe4b2f45ef-c344d7be5b-20168865

- This led to an abundance of the fan-throated lizard, a species only found on the Indian sub continent and a favourite snack of the predatory birds.
- The reptile also had lower levels of the stress hormone corticosterone and this changed how it lived.

- Locally, we have a wide variety of resident raptors, including Golden Eagles, falcons, kestrels, song-birds, tri-colored black birds, bats, horned lizards, black-tailed jack rabbits, and more. We are also in a migratory corridor that will be adversely impacted by the introduction of additional massive wind turbines.

- Previously, the former Campo Landfill site and current Campo Wind site, was found to host Quino Checkerspot butterflies. There is a report.

- There should also be a record of the birds and bats killed by the Kumeyaay Wind turbines. For some reason, that information has been claimed as confidential when the operators don't own the impacted wildlife.

Appropriate wind turbine blade disposal is also critical. They are highly flammable and should not be allowed to be stored on-site or anywhere else within our fire-prone backcountry.

- **They are not recyclable.** Many of the discarded 75 damaged Kumeyaay Wind turbine blades, that were stacked on the ground for years at the base of the turbines, appear to be dumped on the ground at the Jacumba Garage facility on Old Hwy 80. They are a fire hazard in the making and can shed flaming debris that basically floats off-site into the fire-prone chaparral.
- **Unsustainable wind turbine blade disposal practices in the United States**[51]: Katerin RamirezTejeda, David A. Turcotte, Center for Wind Energy, University of Massachusetts Lowell, Mass. Sarah Pike, Political Science and International Relations Department, University of San Diego, Cal. NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy. Volume 26 issue 4 pages 581-598 DOI: 10.1177/1048291116676098: **(Excerpt-emphasis added):**
    - *The material in the shells of the wind turbine blades is typically glass fiber reinforced polymer (GFRP), a resin-matrix material reinforced with fiberglass. In particular, the shells are commonly made from a combination of epoxy resin and glass fiber reinforcement. The blades also contain sandwiched core materials such as polyvinyl chloride foam, polyethylene terephthalate foam, or balsa wood, as well as bonded joints, coatings (polyurethane), and lightning conductors. Conventional epoxy resins are thermosetting materials usually produced by a reaction of epichlorohydrin and bisphenol A in the presence of sodium hydroxide. Both bisphenol A and epichlorohydrin are derived from petrochemicals. Contrary to other types, once cured, thermoset polymers cannot be melted and reshaped by applying heat at high temperatures. As a result, thermoset composites cannot be reformed by any means other than machining, which risks compromising the properties of the material through damage or destruction of the reinforcing fibers. Therefore, the GFRP found in the blades poses a challenge to find or develop more sustainable end-of-life alternatives. …*

[51] https://docs.wind-watch.org/ramireztejeda2016-bladedisposal.pdf

IMPACTS TO MILITARY AND HOMELAND SECURITY ROUTES OF TRAVEL, PRACTICE, AND SURVELIENCE OPERATIONS MUST BE ADDRESSED:

- Local residents are well aware of how often and just how low military and Homeland Security helicopters and other aircraft fly over and around our homes and the area in general.
- The Navy Seals' Posta Warfare Training facility just west of Campo Reservation will be especially hard hit. Their choppers are constantly circling the area, day and night.
- The introduction of 586 foot tall turbines will impede or fully prevent the activities noted above.
- Illegal ground smuggling and human trafficking activities will likely increase locally with reduced air activities. This is just one more adverse impact for local residents that must be addressed.

ALTERNATIVES:

- Ground and/or roof-mounted solar, solar covered parking structures[52], smaller more quiet vertical axis micro wind turbines[53], or geothermal heat pumps[54] can be installed at the Golden Acorn Casino & Truck Stop along with the vacant land west of the Casino parking lot, the Campo Tribal office complex, Campo Materials, The Southern Indian Health Council, Inc., Campo Health Center, Campo Education Center, Campo Reservation Fire Department, and on tribal homes to generate income and to reduce energy costs.
- A small islanded Community Microgrid[55] with solar and small vertical axis wind turbines placed on or near the Golden Acorn Casino, Campo Materials, or elsewhere near existing lines could benefit the Campo Reservation for independence and to help prevent extended power curtailment implemented by San Diego Gas & Electric during extreme weather events.
- Micro-grids are a key recommendation in a recent President's National Advisory Infrastructure Council report[56] on cybersecurity and the grid is that solar and other renewable energy-based microgrids be developed for emergency preparedness. At the same time that solar microgrids can provide refuge from electric grid hacking, the microgrids themselves need to implement security protocols to avoid the same sort of hacking, some experts point out.

Time limits and personal obligations have prevented more in-depth and better formatted comments.
Thank you for consideration.
Any errors or omissions are unintentional

[52] https://www.borregosolar.com/news/the-design-basics-for-solar-parking-lots-you-need-to-know-2
[53] https://cleantechnica.com/2017/10/26/return-vertical-axis-wind-turbine-force-awakens/
[54] https://www.californiageo.org/
DRECP appendix K @page 1 footnote 4: https://www.drecp.org/draftdrecp/
http://www.elcentrochamber.org/news/details/wistaria-ranch-solar-energy-center-project-to-move-forward
[55] http://www.clean-coalition.org/our-work/community-microgrids/
[56] https://cleantechnica.com/2018/12/18/presidents-council-urges-solar-microgrid-use-for-energy-security/

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December 21, 2018

VIA EMAIL
harold.hall@bia.gov

Dan Hall
Acting Chief
Division of Environmental, Cultural Resource Management and Safety
Bureau of Indian Affairs

Re: Scoping Comments of Backcountry Against Dumps and Donna Tisdale on the Campo Wind Project, San Diego County, California

Dear Mr. Hall:

On behalf of Backcountry Against Dumps and Donna Tisdale (collectively, "Backcountry"), we respectfully submit the following scoping comments on the Campo Wind Project ("Campo Wind" or the "Project"), pursuant to the Bureau of Indian Affairs' November 21, 2018 Notice of Intent to Prepare an Environmental Impact Statement for the Proposed Campo Wind Energy Project, San Diego, California ("NOI"), the National Environmental Policy Act ("NEPA"), 42 U.S.C. section 4321 *et seq.*, and the California Environmental Quality Act ("CEQA"), Public Resources Code section 21000 *et seq*. Please include these comments in the public record for this Project.

I. BIA Should Provide More Project Information and Extend the Public Scoping Comment Period

The NOI fails to provide enough detail to adequately inform the public about the Project, which may have dissuaded otherwise interested parties from submitting scoping comments on the Project. For example, neither the NOI nor the Project website (www.campowind.com) provides a map showing specific locations for the up to 60 proposed wind turbines, the onsite collector substation, the 230-kV generation transmission line, or the off-Reservation San Diego Gas & Electric substation and switchyard. The map contained in the scoping meeting presentation has such low resolution that even the legend is illegible. The NOI and Project website also fail to provide other key details, including the length of the proposed transmission line, the setbacks from the turbines and other infrastructure to sensitive receptors and property lines, and the purpose and need for the Project. BIA should issue a new notice of intent that includes the aforementioned information, and provide a new 30-45-day public scoping comment period.

II. NEPA and CEQA Require Thorough Environmental Review of the Project

In addition to the construction and operation of up to 60 wind turbines, the Project would require construction of a new 230-kV overhead generation transmission line, as well as a new substation and switchyard located on private land northeast of the Campo Indian Reservation. 83 Fed. Reg. 58784. The Project will therefore require approval from the California Public Utilities Commission and the County of San Diego, in addition to BIA (collectively, "Approval Agencies"). 83 Fed. Reg. 58785. As a result, the Project – and BIA's Environmental Impact Statement ("EIS") – must comply with NEPA and CEQA, as the NOI states. 83 Fed. Reg. 58785; Public Resources Code § 21083.7.

A. The EIS Must Provide a Full and Accurate Project Description

"An accurate, stable and finite project description is the *sine qua non* of an informative and legally sufficient" environmental impact report ("EIR"). *County of Inyo v. City of Los Angeles* (1977) 71 Cal.App.3d 185, 193. The cornerstone of a useful and NEPA-compliant EIS is similarly an accurate and robust project description.

The Approval Agencies must ensure that the EIS not only corrects the NOI's informational defects, as discussed above, but also provides other critical Project information, including:

- the make and model of the proposed wind turbines;
- how much water the Project would use;
- where the Project would obtain its water supplies;
- what entity would provide firefighting services to the Project;
- how much grading and filling would be required for Project construction; and
- other information essential to understanding, analyzing and determining the environmental impacts of the Project, as discussed below; and

B. The EIS Must Demonstrate a Need for the Project

The Project EIS must show the "underlying purpose and need to which the agency is responding in proposing the alternatives including the proposed action." 40 C.F.R. § 1502.13 (quote); 14 Cal. Code Regs. [CEQA Guidelines] § 15124(b) (EIRs must similarly include a "statement of objectives sought by the proposed projects," including a description of the "underlying purpose of the project"). To satisfy this requirement, the EIS must demonstrate that a need for the project actually exists. *North Carolina Alliance for Transportation Reform v. Department of Transportation*, 151 F.Supp.2d 661, 688 (M.D.N.C. 2001); *Rankin v. Coleman*, 394 F.Supp. 647, 656-7 (E.D.N.C. 1975) (EIS inadequate for failing to cite and discuss factual studies to "show the need for the 'ultimate' five-lane [highway] facility"); *see also* 40 C.F.R. § 1502.24.

The NOI does not even mention the Project purpose, let alone demonstrate a need for the Project. To the contrary, at least four circumstances render the proposed Project unnecessary and inappropriately sited.

First, as reported by the *Los Angeles Times*, Californians are "using less electricity" statewide,[1] which means less need for new industrial-scale energy generation projects. *See also* California Energy Commission ("CEC"), 2017, Electricity Consumption by County (totals from 1990 through 2016, showing peak consumption in 2008).[2] In fact, "power plants are on track to be able to produce at least 21% more electricity than [California] needs by 2020." **Exhibit 1** at 2 (quote); CEC, 2018, Electric Generation Capacity & Energy.[3] California's investor-owned utilities are also well ahead of schedule in meeting the State's Renewables Portfolio Standard ("RPS"). San Diego Gas & Electric, for example, served 43.2 percent of its load with RPS-eligible resources in 2016, far surpassing the RPS requirement of 33 percent by 2020, and close to meeting the 2030 RPS requirement of 60 percent.[4] With California's electricity usage flatlining, renewable energy generation rooftop solar and other distributed generation capacity increasing rapidly, there is less need than ever for remote, industrial-scale projects like the proposed Campo Wind Project - and much less justification for the Project's massive environmental impacts.

Second, industrial-scale wind energy projects rarely generate as much energy as predicted, as a 2015 study confirms.[5] The study's authors conclude that "expanding wind farms to large scales will limit generation rates . . ., thereby constraining mean large-scale generation rates to about 1 Wem-2 even in windy regions." **Exhibit 2** at 11174. This limitation is caused by the wind project itself interfering with and altering the wind patterns in the area. A "greater installed capacity of wind turbines removes more kinetic energy from the atmosphere and coverts it into electric energy, this causes a decrease in the hub-height wind speeds downwind, which decreases the mean per turbine electricity generation rate of the wind farm." **Exhibit 2** at 11171. The "more kinetic energy wind farms use, the greater the shift in the balance and the reduction of wind speeds." **Exhibit 2** at 11169. "[I]t is this decrease in wind speed with greater kinetic energy extraction by more wind turbines that limits the wind power generation at large scales." **Exhibit 2** at 1172. In short, large scale wind energy projects generate diminishing

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[1] Penn, I. and R. Menezes, February 5, 2017, "Californians are paying billions for power they don't need," *Los Angeles Times* (attached hereto as **Exhibit 1**, and also available here: http://www.latimes.com/projects/la-fi-electricity-capacity/).
[2] Available here: http://www.ecdms.energy.ca.gov/elecbycounty.aspx
[3] Available here:
http://www.energy.ca.gov/almanac/electricity_data/electric_generation_capacity.html
[4] California Public Utilities Commission, November 2017, Renewables Portfolio Standard: Annual Report, p. 10 (attached hereto as **Exhibit 2**, and also available here: http://www.cpuc.ca.gov/uploadedFiles/CPUC_Website/Content/Utilities_and_Industries/Energy/Reports_and_White_Papers/Nov%202017%20-%20RPS%20Annual%20Report.pdf)
[5] Miller, L., *et al.*, 2015, "Two methods for estimating limits to large-scale wind power generation," *Proceedings of the National Academy of Sciences* 112(36) (attached hereto as **Exhibit 3**).

returns, as more kinetic energy is removed from the sky and less electricity is delivered to the consumer. Here, the risk of diminished returns is particularly high because the Project would be placed *directly adjacent* to the existing Kumeyaay wind turbines.

Third, wildfire risk in the County is dangerously high, and getting worse with global warming. This risk would both impact and be exacerbated by the Project, which would be located primarily, if not wholly, in a Very High Fire Hazard Severity Zone, as designated by the California Department of Forestry and Fire Protection (CAL FIRE).[6] As reported in the August 2017 Climate Change Vulnerability Assessment for San Diego County,[7] CalAdapt's wildfire tool estimates that under both a low-GHG-emissions scenario and a high-emissions scenario, substantially more land in the County will burn due to wildfire by 2099. San Diego County, Draft Climate Action Plan, Appendix D, p. 12. Under the low-emissions scenario, over 3,500 more acres are expected to burn *every year* by 2099. *Id.* Under a high-emissions scenario, the additional annual acreage scorched by wildfire increases to nearly 8,500. *Id.*

Wildfires triggered by downed or arcing power lines in rural areas such as East County can cause catastrophic losses of lives and property, not to mention wildlife, habitat and scenery. San Diego's catastrophic 2007 Witch Creek Fire, for example, burned 197,990 acres and 1,650 structures, and killed two people. Even more destructive wildfires have recently devastated Butte, Sonoma, Napa, Lake and Mendocino counties in Northern California. The November 2018 Camp Fire was the deadliest wildfire recorded in California history, tragically killing at least 86 people, burning 153,336 acres, and destroying 13,972 residences, 528 commercial buildings and 4,293 other buildings.[8]

The Campo Wind Project would increase the risk of devastating wildfires in San Diego County, particularly in combination with the now-operational Tule Wind Project, and the proposed Torrey Wind Project and Boulder Brush gen-tie project (PDS2018-MPA-18-016). This risk grows each year with the increased temperatures, aridity and severe winds caused by global warming. Such wildfires, in turn, exacerbate global warming by increasing carbon emissions and reducing the shade and moisture that the burned vegetation would have provided.

Fourth, water supplies are increasingly limited and unreliable in the Project area. This is due to growing water demand from development, as well as increasing summer temperatures and resulting aridity. As one 2015 study concluded, "anthropogenic warming is increasing the probability of co-occurring warm-dry conditions like those that have created the acute human

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[6] CAL FIRE, 2009, "Very High Fire Hazard Severity Zones in LRA: As Recommended by CAL FIRE" (attached hereto as **Exhibit 4**, and also available here: http://frap.fire.ca.gov/webdata/maps/san_diego/fhszl_map.37.jpg).

[7] Available here: http://www.sandiegocounty.gov/content/dam/sdc/pds/advance/cap/publicreviewdocuments/CAPfilespublicreview/Appendix%20D%20Climate%20Change%20Vulnerability%20Assessment.pdf

[8] See CAL FIRE's December 14, 2018 "Camp Fire Incident Information," available here: http://www.fire.ca.gov/current_incidents/incidentdetails/Index/2277

and ecosystem impacts associated with the 'exceptional' 2012-2014 drought in California."[9] These co-occurring warm-dry conditions have, in turn, caused unprecedented groundwater depletion due to increased pumping to offset reductions in surface water supplies, as well as reduced groundwater recharge from rain and surface water flows.[10] Recent research using well data from the Central Valley shows that groundwater depletion has long-term effects, including permanent subsidence as aquifers compress or collapse, with the result that subsequent attempts at recharge may be insufficient to restore previous groundwater levels. **Exhibit 6** at 1. The Campo Wind Project area is at particular risk of groundwater supply strain because it lies atop the Campo/Cottonwood Creek Sole Source Aquifer, as discussed further below with respect to hydrology and water supply impacts.[11]

C. The EIS Must Analyze the Whole of the Project and Not Segment the Analysis

NEPA and CEQA both forbid "segmented" or "piecemeal" environmental review. 40 C.F.R. § 1508.25(a)(1); *Berkeley Keep Jets Over the Bay Commission v. Board of Port Commissioners of the City of Oakland* (2001) 91 Cal.App.4th 1344, 1358. Connected actions must be considered together in a single EIS. *Thomas v. Peterson*, 753 F.2d 754, 759 (9th Cir. 1985) (overruled on other grounds by *Cottonwood Environmental Law Center v. U.S. Forest Service*, 789 F.3d 1075, 1088-1092 (9th Cir. 2015)). Environmental concerns must "not become submerged by chopping a large project into many little ones . . . [,] which cumulatively may have disastrous consequences." *Bozung v. Local Agency Formation Commission* (1975) 13 Cal.3d 263, 283-284.

To avoid the segmentation, or piecemealing, prohibited by NEPA and CEQA, the EIS must analyze the impacts of the Campo Wind Project together with the impacts of any connected and cumulative projects, including the Boulder Brush gen-tie project (PDS2018-MPA-18-016), the proposed new San Diego Gas & Electric substation and switchyard, and the transmission line proposed to connect the Project's on-site collector substation to the San Diego Gas & Electric substation.

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[9] Diffenbaugh, N.S., D.L. Swain and D. Touma, March 31, 2015, "Anthropogenic warming has increased drought risk in California," *Proceedings of the National Academy of Sciences* 112(13) (attached hereto as **Exhibit 5**).

[10] Wang, S., Lin, Y., Gillies, R. And Hakala, K., March 2016, "Indications for Protracted Groundwater Depletion after Drought over the Central Valley of California," *Journal of Hydrometeorology* 17:947-955 (attached hereto as **Exhibit 6**); Castle, S.L., Thomas, B.F., Reager, J.T., Rodell, M., Swenson, S.C. and Famiglietti, J.S., 2014, "Groundwater Depletion During Drought Threatens Future Water Security of the Colorado River Basin," *Geophysical Research Letters*, 41:5904-5911 (attached hereto as **Exhibit 7**).

[11] A map of the sole source aquifer is available here: https://archive.epa.gov/region9/water/archive/web/pdf/campo-cottonwood-ssa-map.pdf

D. The EIR Must Analyze the Full Range of Project Impacts and Measures to Mitigate Them.

The Approval Agencies must take a "hard look" at the potentially significant environmental impacts from the Project, and provide a "full and fair discussion" of those impacts in the EIS. 40 C.F.R. § 1502.1; *National Parks and Conservation Association v. BLM*, 606 F.3d 1058, 1072-1073 (9th Cir. 2010); CEQA Guidelines § 15126.2(a) ("Direct and indirect significant effects of the project on the environment shall be clearly identified and described"). Among other impacts, the Project would likely substantially and negatively impact birds, bats, other wildlife, humans (e.g. through Project-generated noise and magnetic field radiation), land use plan consistency, climate change, hydrology and water supplies, fire risk and emergency services, aesthetics, and property values. The EIS must fully analyze these and other impacts.

<u>Bird Impacts</u>

Wind turbines kill birds.[12] The Campo Wind Project's 60 turbines will be no different. A wealth of bird species have been documented inhabiting or otherwise using the Project area, including sensitive species like golden eagles. For example, a study of the nearby Tule Wind Project area identified at least 10 golden eagle territories within approximately 10 miles of the area.[13] The risk to golden eagles is particularly concerning because they are "currently known to be at risk of *population-level* effects from [wind turbine] collisions," and must be afforded every possible protection. **Exhibit 8** at 306.

In addition to killing and maiming birds through collisions with blades and related structures and powerlines,[14] wind turbines can also cause significant *landscape*-scale avoidance impacts.[15] A recent longitudinal study of bird densities at 12 wind farms in Ireland and their paired control sites found that "densities of open-habitat species were lower at wind farms" than at the control sites "independent of distance to turbines." **Exhibit 10** at 7. This "suggests that for open-habitat birds, effects were operating at a landscape scale." **Exhibit 10** at 8. The Campo Wind Project could well have similar effects. While the bird species may be different near the Campo Wind Project site than at the study sites in Ireland, the terrain is more "open-habitat" than

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[12] Dwyer, J.F., M.A. Landon, and E.K. Mojica, 2018, "Impact of Renewable Energy Sources on Birds of Prey," in J.H. Sarasola *et al.* (eds.), 2018, *Birds of Prey*, Springer International Publishing AG (attached hereto as **Exhibit 8**).
[13] *See* BLM and CPUC, Draft Environmental Impact Report/Environmental Impact Statement for East County Substation, Tule Wind, and Energia Sierra Juarez Gen-Tie Projects, December 2010, p. D.2-46, available at: http://www.cpuc.ca.gov/environment/info/dudek/ECOSUB/Draft_EIR/D-2_BioResources.pdf
[14] *See*, *e.g.*, Smallwood, S.K., and B. Karas, 2009, "Avian and Bat Fatality Rates at Old-Generation and Repowered Wind Turbines in California," *The Journal of Wildlife Management* 73(7) (attached hereto as **Exhibit 9**).
[15] Fernández-Bellon, D., M.W. Wilson, S. Irwin, and J. O'Halloran, 2018, "Effects of Development of Wind Energy and Associated Changes in Land Use on Bird Densities in Upland Areas," *Conservation Biology* 0(0):1-10 (attached hereto as **Exhibit 10**).

"forested" (the other type of habitat present at some of the Ireland study sites, and for which the authors found gradient rather than landscape effects).

A further risk factor is that the Campo Wind Project would have so many turbines – up to 60. The Irish study found that bird densities decreased with wind farm size (number of turbines). **Exhibit 10** at 7. And the Campo Wind Project would have almost double the number of turbines than the largest wind farm in the Irish study (35 turbines).

Wind turbines can also cause long-term harm to birds through impacts on their migration patterns. **Exhibit 8**. For example, a 2016 study investigating "how anthropogenic mortality can influence the migratory pattern of a partial migrant," concluded that "human-induced mortality may be an important factor modifying" migration patterns and could possibly lead to the complete cessation of migration for an entire species.[16] **Exhibit 11** at 4.

The 2016 study identified a sharp decline in the proportion of male great bustards that were migratory (rather than sedentary) from 86 percent of the total population at the beginning of the study, to just 44 percent at the end. **Exhibit 11** at 15. Migrating males suffered far greater mortality from powerlines and other human disturbances than did the sedentary population, leading to a dramatic loss of the birds who historically lead their flocks on the periodic migrations needed for long term survival of the species. Loss of these migration "leaders" caused, in turn, a sharp decline in the proportion of young birds who had learned how to lead migrations from the older males who were disproportionately killed by powerlines and other disturbances. This study concluded that social learning leads to fewer yearly migrants because "immature birds will have more sedentary adults from which to learn their own strategy." *Id.* This tragic loss of migration skills and resulting decline in successful migrations will only get worse over time and will lead to increased competition for resources, reduced genetic diversity, impaired gene flow, and potentially the cessation of migration "lead[ing] to the extinction of the population." *Id.*

These migratory impacts are not limited to the great bustard, and can have significant effects on golden eagles, raptors, and other species that migrate through or near the proposed Project's highly destructive wind turbines. According to a recent study on mitigations for wind turbine induced avian mortality, "the cumulative effect of mortality from anthropogenic sources may be detrimental," or even "fatal" to some species.[17] "[C]ontinuous exposure to a certain risk may lead to increased discrimination (latent inhibition), but decreased associability (habituation)." **Exhibit 12** at 172. Avian exposure to wind turbines and potential visual or acoustic deterrence measures, may cause migrating birds "to move away from the wind-power

[16] Palacín, C., J.C. Alonso, C.A. Martín, and J.A. Alonso, 2016, "Changes in Bird Migration Patterns Associated With Human-Induced Mortality," *Conservation Biology*, 31(1) (attached hereto as **Exhibit 11**).
[17] May, R., O. Reitan, K. Bevanger, S.H. Lorentsen, and T. Nygard, 2014, "Mitigating wind-turbine induced avian mortality: Sensory, aerodynamic and cognitive constraints and options," *Renewable and Sustainable Energy Reviews*, 42:170-181 (attached hereto as **Exhibit 12**).

plant area to other possibly suboptimal habitat." **Exhibit 12** at 177. "The effect of [this avoidance] on the entire population may therefore be larger than the" already significant "effect of some birds colliding with wind turbines." *Id*.

Through the aforementioned mechanisms and others, the Project will almost assuredly kill and otherwise seriously harm local and migratory bird species. As a result, not only must the Approval Agencies analyze those impacts in the EIS prior to considering Project approval, Project operation may be *entirely prohibited* under other federal and state laws.

For example, golden eagles are protected by the Bald and Golden Eagle Protection Act ("BGEPA"), 16 U.S.C. section 668-668(d), and the Migratory Bird Treaty Act ("MBTA"), 16 U.S.C. section 703 *et seq.* The BGEPA prohibits the "take" – including the wounding or killing – of golden and bald eagles in the United States, unless specially permitted by the U.S. Fish and Wildlife Service. 16 U.S.C. § 668; 50 C.F.R. § 22.26. The MBTA more broadly prohibits the take of "*any* migratory bird" listed in 50 C.F.R. Part 10.13, which includes golden eagles. 16 U.S.C. § 703(a) (emphasis added). And the Fish and Wildlife Service's regulations only permit taking migratory birds for limited purposes, including taxidermy, scientific collection, and banding or marking, among other constrained purposes, none of which apply to the proposed wind energy use. 50 C.F.R. Part 21.

California Fish and Game Code section 3511 likewise prohibits the "take" of any "fully protected birds," which include golden eagles (common to the Project site). Fish and Game Code section 3513 also prohibits the "take" of "any migratory nongame bird as designated in the [federal] Migratory Bird Treaty Act," except as authorized by the Secretary of the Interior.

Bat Impacts

Bats perform a vital biological function by preying on insects including disease-bearing mosquitoes. But as with birds, wind turbines also kill bats, through both collisions and barotrauma (abrupt drop in air pressure behind turbine blades sucks bats into low pressure zone, causing bats' lungs to expand and hemorrhage). And with "continued wind energy expansion, there are increasing concerns that there could be population-level implications for bats."[18] **Exhibit 13** at 125. This is even more concerning given recent evidence that bats are *attracted* to wind turbines and associated infrastructure, and use them as night or foraging roosts. **Exhibit 13**. The EIS must analyze the Project's impacts to bats.

Other Wildlife and Ecosystem Impacts

The EIS must also analyze the Project's impacts to the wide range of other plants, animals and ecosystems on the Project site or otherwise affected by the Project, including sensitive plant and animal species protected by the federal Endangered Species Act or the

[18] Bennett, V.J., A.M. Hale, and D.A. Williams, 2017, "When the Excrement Hits the Fan: Fecal Surveys Reveal Species-Specific Bat Activity at Wind Turbines," *Mammalian Biology* 87:125-129 (attached hereto as **Exhibit 13**).

California Endangered Species Act. The Project area is ecologically sensitive, as indicated by the fact that it is entirely located in the East County Planning Area of the draft Multiple Species Conservation Program.[19]

The EIS must also look beyond direct impacts to individual species. It must analyze ecosystem-level impacts, including the cascading impacts across trophic levels that can occur when wind turbines "reduc[e] the impact of predatory birds in the area."[20] **Exhibit 14** at 1856. For example, a recent study of the ecosystem impacts of wind turbines in India found that "wind farms reduce the abundance of predatory birds . . ., which consequently increases the density of lizards." **Exhibit 14** at 1854. More broadly, the authors concluded that "anthropogenic disturbances such as wind farms act as effective apex predators. By reducing the impact of predatory birds in the area, wind turbines cause a cascade of changes in terrestrial prey, driven primarily by the ecological processes of predator release and density-mediated competition." **Exhibit 14** at 1856.

Noise Impacts

The Approval Agencies must analyze the Project's noise impacts in the EIS, and also ensure that it complies with the County's Noise Ordinance and its Wind Energy Ordinance. That analysis must also cover the health impacts of wind turbine-generated noise, including stress, sleep disturbance and reduced quality of life.

Most wind turbine noise impact studies to date have assessed the relationship between noise and self-reported annoyance or sleep disturbance. But researchers are increasingly studying the physiological responses to wind turbine noise during sleep. For example, a pair of recent pilot studies investigated the physiologically measured sleep effects of nocturnal wind turbine noise in a laboratory setting.[21] The results provided "evidence that participants had more frequent awakenings, reduced amounts of N3 ("deep") sleep, reduced continuous N2 sleep, increased self-reported disturbance and [wind turbine noise]-induced tiredness in exposure nights with [wind turbine noise] compared to [wind turbine noise]-free nights." **Exhibit 15** at 10. The increase in self-reported sleep disturbance also comport with numerous survey-based studies on the subject.

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[19] A draft map of the East County Planning Area is available here: https://www.sandiegocounty.gov/content/dam/sdc/pds/mscp/docs/ECMSCP/east_mscp_csa2_2_8x11.pdf

[20] Thaker, M., A. Zambre, and H. Bhosale, 2018, "Wind Farms Have Cascading Impacts on Ecosystems across Trophic Levels," *Nature Ecology & Evolution* 2:1854-1858 (attached hereto as **Exhibit 14**).

[21] Morsing, J.A., M.G. Smith, M. Ögren, P. Thorsson, E. Pedersen, J. Forssén, and K.P Waye, 2018, "Wind Turbine Noise and Sleep: Pilot Studies on the Influence of Noise Characteristics," *International Journal of Environmental Research and Public Health*, 15(2573) (attached hereto as **Exhibit 15**).

In a 2015 peer-reviewed journal article, researchers "explore[d] the association between wind turbine noise, sleep disturbance and quality of life, using data from published observational studies."[22] **Exhibit 16** at 1. Through a meta-analysis of six studies, they "revealed that the odds of being annoyed is significantly increased by wind turbine noise (OR: 4.08; 95% CI: 3.37 to 7.04; p<0.00001)," and the "odds of sleep disturbance was also significantly increased with greater exposure to wind turbine noise (OR: 2.94; 95% CI: 1.98 to 4.37; p < 0.00001)." *Id.* In addition, four of the studies they analyzed "reported that wind turbine noise significantly interfered with [quality of life]." *Id.*

An even more recent literature review similarly concluded that the published literature "suggest[s] that exposure to wind turbine sound is associated with higher odds for annoyance."[23] **Exhibit 17** at 53. So too did a 2014 literature review, stating that "it seems reasonable to conclude that noise from wind turbines increases the risk of annoyance and disturbed sleep in exposed subjects in a dose-response relationship," with a "tolerable limit of around LAeq of 35 dB."[24] **Exhibit 18** at 22. But audible wind turbine noise, as typically measured with A-weighted sound pressure levels, is not the only source of disturbance and physiological impact.

A 2018 review of the scientific literature affirmed not only that "there is ample evidence demonstrating that a component of the sound energy produced by a [wind turbine] is in the low and infrasonic frequency range," but also that the literature presents a "strong prima facia case for neural transduction of low-frequency sound] and [infrasound]."[25] **Exhibit 19** at 2 (first quote), 6 (second quote). That review also noted that weighted noise measurements – like the A-weighted measurements typically done for audible noise impact analyses, and the C-weighted measurements required by San Diego County Zoning Code section 6952(f)(1) – "exclude crucial low frequencies" from wind turbines. **Exhibit 19** at 3.

A-weighting "do[es] not give a valid representation of whether wind turbine noise affects the ear or other aspects of human physiology mediated by the [outer hair cells] and unrelated to hearing."[26] **Exhibit 20** at 299. "While normal sound perception depends on *inner* hair cell

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[22] Onakpoya, I.J., J. O'Sullivan, M.J. Thompson, and C.J. Henghan, 2015, "The Effect of Wind Turbine Noise on Sleep and Quality of Life: A Systematic Review and Meta-analysis of Observational Studies," *Environment International* 82:1-9 (attached hereto as **Exhibit 16**).
[23] van Kamp, I., and F. van den Berg, 2018, "Health Effects Related to Wind Turbine Sound, Including Low-Frequency Sound and Infrasound," *Acoustics Australia* 46(1):31-57 (attached hereto as **Exhibit 16**).
[24] Schmidt, J.H., and M. Klokker, 2014, "Health Effects Related to Wind Turbine Noise Exposure: A Systematic Review," *PLoS ONE* 9(12) (attached hereto as **Exhibit 18**).
[25] Carlile, S., J.L. Davy, D. Hillman, and K. Burgemeister, 2018, "A Review of the Possible Perceptual and Physiological Effects of Wind Turbine Noise," *Trends in Hearing* 22:1-10 (attached hereto as **Exhibit 19**).
[26] Salt, A., and J. Kaltenbach, 2011, "Infrasound from Wind Turbines Could Affect Humans," *Bulletin of Science, Technology and Society*, 31(4): 296-302 (attached hereto as **Exhibit 20**).

(IHC) function, human sensitivity to infrasound and low frequencies is thought to rely heavily on *outer* hair cells (OHCs)."[27] **Exhibit 21** at 52.

With respect to impact thresholds, research indicates that because the ear's electrical responses to infrasound and low-frequency noise "stimulation are larger" than its responses to audible noise, "and do not saturate [*i.e.*, reach an impact plateau] to the degree seen when higher-frequency components are present," it takes far *less* sound pressure (lower decibel level) for infrasound and low-frequency noise to cause measurable impacts than it takes for audible noise to have such effects.[28] **Exhibit 22** at 4. Put another way, infrasound causes far more measurable impacts – decibel for decibel – than does audible noise. As one study found, OHCs "could be stimulated [by very low frequency sounds] at levels up to 40 dB *below* those that stimulate the IHC" and can be heard.[29] **Exhibit 23** at 16 (original emphasis).

The EIS must analyze the Project's audible, low-frequency and infrasound noise impacts. The noise analysis should therefore include unweighted noise measurements and estimates, as well as the A- and C-weighted estimates commonly used in noise impact analyses.

Magnetic Field Radiation Impacts

"Magnetic field (MF) non-ionizing radiation is a ubiquitous environmental exposure and a serious looming public health challenge."[30] **Exhibit 24** at 1. The International Agency for Research on Cancer classifies MF radiation as a possible carcinogen. **Exhibit 24** at 1. And a recent study found that higher MF exposure is associated with an increased risk of miscarriage in pregnant women. **Exhibit 24**.

Power lines and transformers emit MFs, and are both integral Project components. **Exhibit 24** at 1; **Exhibit 8**. The EIR must analyze the impacts on humans and wildlife alike of the Project's MF radiation.

Greenhouse Gas Emission and Climate Change Impacts

The EIS must analyze not only the greenhouse gas emissions from Project construction and operation, but also its lifecycle emissions, including those associated with both the

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[27] Chen, H.A., and P. Narins, 2012, "Wind Turbines and Ghost Stories: The Effects of Infrasound on the Human Auditory System," *Acoustics Today,* 8(2):51-55 (attached hereto as **Exhibit 21**),
[28] Salt, A., and J. Lichtenhan, 2012, "Perception-based protection from low-frequency sounds may not be enough," presented at InterNoise 2012 in New York City, New York, August 19-22, 2012 (attached hereto as **Exhibit 22**).
[29] Salt, A., and T. Hullar, 2010, "Responses of the Ear to Low Frequency Sounds, Infrasound and Wind Turbines," *Hearing Research*, 268:12-21 (attached hereto as **Exhibit 23**).
[30] Li, D-K, H. Chen, J.R. Ferber, R. Odouli, and C. Quesenberry, 2017, "Exposure to Magnetic Field Non-Ionizing Radiation and the Risk of Miscarriage: A Prospective Cohort Study," *Scientific Reports* 7:17541 (attached hereto as **Exhibit 24**).

manufacturing and the transporting of the wind turbines, the towers on which they are placed, and the powerlines that deliver their energy.

Hydrology and Water Supply Impacts

As discussed above in section II(B), water supplies are increasingly limited and unreliable in the Project area. The EIS must identify the likely sources of water supply for the Project and analyze the "reasonably foreseeable impacts of supplying [that] water." *Vineyard Area Citizens for Responsible Growth v. City of Rancho Cordova* (2007) 40 Cal.4th 412, 434. As part of that analysis, the EIS must assess the Project's impacts to the Campo/Cottonwood Creek Aquifer. The aquifer was designated as a sole source aquifer pursuant to section 1424(e) of the federal Safe Drinking Water Act on May 28, 1993, with the Environmental Protection Agency ("EPA") making the determination that "contamination of [the] aquifer would create a significant hazard to public health." 58 Fed. Reg. 31025 (May 28, 1993). As a result of this designation, before the Project can receive any federal funds it is "subject to EPA review to ensure that [it is] designed so as not to create a significant hazard to public health." *Id.*

Fire Impacts and Emergency Services

As discussed above in section II(B), wildfire risk in San Diego County is dangerously high, and getting worse with global warming. This risk would both impact and be exacerbated by the Campo Wind Project and related projects, including the proposed new San Diego Gas & Electric substation and switchyard to which the Campo Wind Project would connect, the Boulder Brush gen-tie project and the Torrey Wind project. The EIS must analyze these impacts, as well as the impact to effective firefighting and emergency services in the area.

Aesthetic Impacts

The EIS must analyze the panoply of visual impacts the Project's wind turbines and other infrastructure would have on local scenery, aesthetic enjoyment and human health. That includes shadow flicker. The Minnesota Department of Health stated in a report on the public health impacts of wind turbines that the "[r]hythmic light flicker from the blades of a wind turbine casting intermittent shadows has been reported to be annoying in many locations."[31] **Exhibit 25** at 14. Shadow flicker can also present numerous dangers, such as distracting drivers on roads close to turbines.

Property Value Impacts

Strong evidence exists that wind energy facilities can "negatively impact[] surrounding property values."[32] **Exhibit 26** at 514. Those impacts have been shown to "increase with the

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[31] Minnesota Department of Health, Environmental Health Division, "Public Health Impacts of Wind Turbines," Report prepared May 22, 2009 (attached hereto as **Exhibit 25**).
[32] Vyn, R.J., 2018, "Property Value Impacts of Wind Turbines and the Influence of Attitudes toward Wind Energy," *Land Economics*, 94(4):496-516 (attached hereto as **Exhibit 26**).

number of turbines in close proximity," and to also be greater in communities that are less receptive to wind energy facilities being sited there. **Exhibit 26** at 514. The EIS must analyze these impacts as part of the socioeconomic analysis identified in the NOI.

E. The EIS Must Analyze a Full Range of Project Alternatives

NEPA requires that EISs "[r]igorously explore and objectively evaluate all reasonable alternatives" so that "reviewers may evaluate their comparative merits." 42 U.S.C. §4332; 40 C.F.R. § 1502.14. Alternatives should be wide-ranging and not exclude options just because they require other agency approvals. *Sierra Club v. Lynn*, 502 F.2d 43, 62 (5th Cir. 1974). Agencies may decline to study an alternative in detail on the grounds that it is "similar to alternatives actually considered, or . . . infeasible, ineffective, or inconsistent with the basic policy objectives for the management area," but only after providing a "reasoned explanation *in the EIS* for its rejection." *Northern Alaska Environmental Center v. Kempthorne*, 457 F.3d 969, 978 (9th Cir. 2006) (internal quotations and citation omitted); *Southeast Alaska Conservation Council v. Federal Highway Administration*, 649 F.3d 1050, 1059 (9th Cir. 2011). The existence of a viable but unexamined alternative renders an environmental impact statement inadequate." *Friends of Yosemite Valley v. Kempthorne*, 520 F.3d 1024, 1038 (9th Cir. 2008).

CEQA similarly requires EIRs to "describe a range of reasonable alternatives to the project . . . which would feasibly attain most of the basic objectives of the project but would avoid or substantially lessen any of the significant effects of the project, and evaluate the comparative merits of the alternatives." Guidelines § 15126.6(a). Alternatives that would lessen significant effects should be considered even if they "would impede to some degree the attainment of the project objectives, or be more costly." *Id.* § 15126.6(b). The range of alternatives considered must "foster informed decisionmaking and public participation." *Id.* § 15126.6(a). Alternatives may only be eliminated from "detailed consideration" when substantial evidence in the record shows that they either (1) "fail[] to meet most of the basic project objectives," (2) are "infeasibl[e]," or (3) do not "avoid significant environmental impacts." *Id.* § 15126.6(c).

Energy conservation and other less impactful alternatives than utility-scale wind projects exist to conserve or generate electricity from renewable sources. For example, the EIS should analyze programs to develop or incentivize the development of distributed photovoltaic ("PV") generation projects near energy demand centers in already-disturbed areas. Beyond traditional distributed generation, a recent study shows that installing PV and concentrating solar power ("CSP") technologies throughout California's built environment could substantially exceed the state's forecasted 2020 energy needs.[33] Another recent study estimates that deploying PV and CSP solely on developed land (built environment), land with salt-affected soils, contaminated land and reservoirs in California's Central Valley "could meet CA's projected 2025 needs for electricity consumption between 10-13 times over" (for PV technologies) and "over two times

[33] Hernandez, R.R., M.K. Hoffacker, M.L. Murphy-Mariscal, G. Wu, and M.F. Allen, 2015, "Solar Energy Development Impacts on Land-Cover Change and Protected Areas," *Proceedings of the National Academy of Sciences*, 112(44) (attached hereto as **Exhibit 27**).

over with CSP technologies."[34] **Exhibit 28** at 14479. The EIS must analyze these environmentally superior alternatives.

III. The Project Must Comply with CPUC General Order 131-D.

The NOI states that the Project would include a 230-kV transmission line connecting to a new San Diego Gas & Electric substation and switchyard, both of whose environmental impacts the EIS will analyze. The EIS must discuss, and the Approval Agencies must ensure, the Project's compliance with the California Public Utilities Commission's General Order 131-D. For example, the Project requires a certificate of public convenience and necessity because it includes "major electric transmission line facilities which are designed for immediate or eventual operation at 200 kV or more." G.O. 131-D § III(A).

IV. Conclusion

For each of the foregoing reasons, the Project cannot be approved without extensive environmental analysis and regulatory permitting. The EIS' alternatives analysis is particularly important, given that under applicable laws, the proposed Project's avian impacts may preclude Project operation as currently proposed.

Respectfully submitted,

Stephan C. Volker
Attorney for Backcountry Against Dumps
and Donna Tisdale

SCV:taf

Attachments:

Exhibit 1 – Penn, I. and R. Menezes, February 5, 2017, "Californians are paying billions for power they don't need," *Los Angeles Times* (available here: http://www.latimes.com/projects/la-fi-electricity-capacity/).

Exhibit 2 – California Public Utilities Commission, November 2017, Renewables Portfolio Standard: Annual Report, p. 10 (available here: http://www.cpuc.ca.gov/uploadedFiles/CPUC_Website/Content/Utilities_and_Industries/Energy/Reports_and_White_Papers/Nov%202017%20-%20RPS%20Annual%20Report.pdf).

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[34] Hoffacker, M.L., M.F. Allen, and R.R. Hernandez, 2017, "Land-Sparing Opportunities for Solar Energy Development in Agricultural Landscapes: A Case Study of the Great Central Valley, CA, United States," *Environmental Science & Technology* 51:14472-14482 (attached hereto as **Exhibit 28**).

Exhibit 3 – Miller, L., *et al.*, 2015, "Two methods for estimating limits to large-scale wind power generation," *Proceedings of the National Academy of Sciences* 112(36).

Exhibit 4 – CAL FIRE, 2009, "Very High Fire Hazard Severity Zones in LRA: As Recommended by CAL FIRE" (available here: http://frap.fire.ca.gov/webdata/maps/san_diego/fhszl_map.37.jpg).

Exhibit 5 – Diffenbaugh, N.S., D.L. Swain and D. Touma, March 31, 2015, "Anthropogenic warming has increased drought risk in California," *Proceedings of the National Academy of Sciences* 112(13).

Exhibit 6 – Wang, S., Lin, Y., Gillies, R. And Hakala, K., March 2016, "Indications for Protracted Groundwater Depletion after Drought over the Central Valley of California," *Journal of Hydrometeorology* 17:947-955.

Exhibit 7 – Castle, S.L., Thomas, B.F., Reager, J.T., Rodell, M., Swenson, S.C. and Famiglietti, J.S., 2014, "Groundwater Depletion During Drought Threatens Future Water Security of the Colorado River Basin," *Geophysical Research Letters*, 41:5904-5911.

Exhibit 8 – Dwyer, J.F., M.A. Landon, and E.K. Mojica, 2018, "Impact of Renewable Energy Sources on Birds of Prey," in J.H. Sarasola *et al.* (eds.), 2018, *Birds of Prey*, Springer International Publishing AG.

Exhibit 9 – Smallwood, S.K., and B. Karas, 2009, "Avian and Bat Fatality Rates at Old-Generation and Repowered Wind Turbines in California," *The Journal of Wildlife Management* 73(7).

Exhibit 10 – Fernández-Bellon, D., M.W. Wilson, S. Irwin, and J. O'Halloran, 2018, "Effects of Development of Wind Energy and Associated Changes in Land Use on Bird Densities in Upland Areas," *Conservation Biology* 0(0):1-10

Exhibit 11 – Palacín, C., J.C. Alonso, C.A. Martín, and J.A. Alonso, 2016, "Changes in Bird Migration Patterns Associated With Human-Induced Mortality," *Conservation Biology*, 31(1).

Exhibit 12 – May, R., O. Reitan, K. Bevanger, S.H. Lorentsen, and T. Nygard, 2014, "Mitigating wind-turbine induced avian mortality: Sensory, aerodynamic and cognitive constraints and options," *Renewable and Sustainable Energy Reviews*, 42:170-181.

Exhibit 13 – Bennett, V.J., A.M. Hale, and D.A. Williams, 2017, "When the Excrement Hits the Fan: Fecal Surveys Reveal Species-Specific Bat Activity at Wind Turbines," *Mammalian Biology* 87:125-129.

Exhibit 14 – Thaker, M., A. Zambre, and H. Bhosale, 2018, “Wind Farms Have Cascading Impacts on Ecosystems across Trophic Levels,” *Nature Ecology & Evolution* 2:1854-1858 (attached hereto as **Exhibit 14**).

Exhibit 15 – Morsing, J.A., M.G. Smith, M. Ögren, P. Thorsson, E. Pedersen, J. Forssén, and K.P Waye, 2018, “Wind Turbine Noise and Sleep: Pilot Studies on the Influence of Noise Characteristics,” *International Journal of Environmental Research and Public Health*, 15(2573).

Exhibit 16 – Onakpoya, I.J., J. O’Sullivan, M.J. Thompson, and C.J. Henghan, 2015, “The Effect of Wind Turbine Noise on Sleep and Quality of Life: A Systematic Review and Meta-analysis of Observational Studies,” *Environment International* 82:1-9.

Exhibit 17 – van Kamp, I., and F. van den Berg, 2018, “Health Effects Related to Wind Turbine Sound, Including Low-Frequency Sound and Infrasound,” *Acoustics Australia* 46(1):31-57.

Exhibit 18 – Schmidt, J.H., and M. Klokker, 2014, “Health Effects Related to Wind Turbine Noise Exposure: A Systematic Review,” *PLoS ONE* 9(12).

Exhibit 19 – Carlile, S., J.L. Davy, D. Hillman, and K. Burgemeister, 2018, “A Review of the Possible Perceptual and Physiological Effects of Wind Turbine Noise,” *Trends in Hearing* 22:1-10

Exhibit 20 – Salt, A., and J. Kaltenbach, 2011, “Infrasound from Wind Turbines Could Affect Humans,” *Bulletin of Science, Technology and Society*, 31(4): 296-302.

Exhibit 21 – Chen, H.A., and P. Narins, 2012, “Wind Turbines and Ghost Stories: The Effects of Infrasound on the Human Auditory System,” *Acoustics Today,* 8(2):51-55.

Exhibit 22 – Salt, A., and J. Lichtenhan, 2012, “Perception-based protection from low-frequency sounds may not be enough,” presented at InterNoise 2012 in New York City, New York, August 19-22, 2012.

Exhibit 23 – Salt, A., and T. Hullar, 2010, “Responses of the Ear to Low Frequency Sounds, Infrasound and Wind Turbines,” *Hearing Research*, 268:12-21.

Exhibit 24 – Li, D-K, H. Chen, J.R. Ferber, R. Odouli, and C. Quesenberry, 2017, “Exposure to Magnetic Field Non-Ionizing Radiation and the Risk of Miscarriage: A Prospective Cohort Study,” *Scientific Reports* 7:17541.

Exhibit 25 – Minnesota Department of Health, Environmental Health Division, “Public Health Impacts of Wind Turbines,” Report prepared May 22, 2009.

Exhibit 26 – Vyn, R.J., 2018, "Property Value Impacts of Wind Turbines and the Influence of Attitudes toward Wind Energy," *Land Economics*, 94(4):496-516.

Exhibit 27 – Hernandez, R.R., M.K. Hoffacker, M.L. Murphy-Mariscal, G. Wu, and M.F. Allen, 2015, "Solar Energy Development Impacts on Land-Cover Change and Protected. Areas," *Proceedings of the National Academy of Sciences*, 112(44).

Exhibit 28 – Hoffacker, M.L., M.F. Allen, and R.R. Hernandez, 2017, "Land-Sparing Opportunities for Solar Energy Development in Agricultural Landscapes: A Case Study of the Great Central Valley, CA, United States," *Environmental Science & Technology* 51:14472-14482.

Hall, Harold <harold.hall@bia.gov>

[EXTERNAL] Email #1 of 4 - Scoping Comments on Campo Wind Project, San Diego, California and Exhibits 01 - 05

1 message

Stephan Volker <svolker@volkerlaw.com> Fri, Dec 21, 2018 at 1:43 PM
To: harold.hall@bia.gov

Dear Mr. Hall,

Attached please find the scoping comment letter (and 28 exhibits thereto) submitted on behalf of Backcountry Against Dumps and Donna Tisdale on the Campo Wind Project pursuant to the Bureau of Indian Affairs' November 21, 2018 Notice of Intent to Prepare and Environmental Impact Statement for the Proposed Campo Wind Energy Project, San Diego, California, the National Environmental Policy Act, 42 U.S.C. section 4321 et seq., and the California Environmental Quality Act, Public Resources Code section 21000 et seq.

Because of the large size of the 28 exhibits, we are transmitting with this email the scoping comment letter and Exhibits 01 - 05. The remaining exhibits are being sent to you via separate emails.

Please include these comments and the exhibits in the public record for this Project.

Respectfully submitted,

Stephan C. Volker

Attorney for Backcountry Against Dumps and Donna Tisdale

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6 attachments

Scoping Comments of Backcountry Against Dumps re Campo Wind Project 2018-12-21.pdf
189K

Exhibit 01.pdf
1298K

Exhibit 02.pdf
1364K

Exhibit 03.pdf
895K

Exhibit 04.pdf
229K

Exhibit 05.pdf
1559K

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KUMEYAAY AND OCOTILLO WIND TURBINE FACILITIES

NOISE MEASUREMENTS

28 February 2014

Submitted to:

Stephan C. Volker, Esq.

Law Offices of Stephan C. Volker

Submitted by:

Richard A. Carman, Ph.D., P.E.

Michael A. Amato

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EXECUTIVE SUMMARY

Noise measurements were obtained for wind turbines (WTs) at the Kumeyaay Wind Farm (Kumeyaay Wind) and Ocotillo Wind Energy Facility (Ocotillo Wind or OWEF) between April 28 and April 30, 2013. This report conclusively documents the presence of infrasound and low frequency noise (ILFN) generated by the two facilities' wind turbines at residential and other locations up to 6 miles from the wind turbines.

It is clear from the measured noise data obtained from Kumeyaay and Ocotillo facilities that there is significant wind turbine-generated ILFN. This was to be expected as it has been documented by others such as in the McPherson noise study, the Shirley Wind Turbine study, and by Epsilon Associates.[1] And indeed the measured ILFN levels near Kumeyaay and Ocotillo wind turbine facilities are similar to those measured in previous studies after accounting for the proximity of the measurements to a wind turbine and the total number of the wind turbines in the facility.

Both the McPherson and Shirley wind turbine noise studies were conducted to investigate whether and at what levels the subject wind turbines (the turbines in Falmouth, Massachusetts, and those in the Shirley Wind Project in Brown County, Wisconsin) produce ILFN, and whether that ILFN was contributing to the significant health and other impacts reported by nearby residences. In some cases, the impacts were so severe that residents abandoned their homes. Both studies found high levels of wind turbine-generated ILFN at numerous nearby residences that correlated with residents' reported impacts.

Human health impacts from wind turbines had been reported previously in several countries with large wind facilities in proximity to residences. But these impacts were often attributed to certain individuals' aversion to the presence of a large industrial facility constructed in what was previously a quiet rural setting. Scientific understanding has developed significantly since then.

Recent research and investigations into human response to ILFN seem to provide strong evidence of a cause and effect relationship. In particular the work of Salt, et al.[2] has made a clear case for perception of ILFN below the threshold of hearing as defined by ISO 389-7 which is related to the response of the ear's inner hair cells (IHC). Salt has demonstrated that it is possible for the ears' outer hair cells (OHC) to respond to ILFN at sound pressure levels that are much lower than the IHC threshold. Salt has reported that ILFN levels (levels commonly generated by wind turbines nearby residences) can cause physiologic changes in the ear.[3] Salt and Kaltenbach "estimated that sound levels of 60 dBG will stimulate the OHC of the human ear."[4]

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[1] Epsilon Associates, A Study of Low Frequency and Infrasound from Wind Turbines, July 2009.

[2] Alec Salt, and J. Lichtenhan, Perception based protection from low-frequency sounds may not be enough, Internoise 2012, August 2012.

[3] Alec Salt, and J.A. Kaltenbach, "Infrasound from Wind Turbines Could Affect Humans," Bulletin of Science, Technology and Society, 31(4), pp.296-302, September 12, 2011.

[4] Ibid., p. 300, "As discussed below, G-weighting (with values expressed in dBG) is one metric that is used to quantify environmental noise levels. While it is a more accurate measure of ILFN than most other metrics, G-weighting still de-emphasizes infrasound."

Furthermore, Matsumoto et al.[5] have demonstrated in a laboratory setting that humans can perceive ILFN at sound pressure levels below the IHC threshold when the noise is a complex spectrum (i.e. contains multiple frequency components). From this laboratory research it was clearly demonstrated that humans can perceive sound pressure levels that are from 10 to 45 decibels (dB) less than the OHC threshold in the ILFN range. In fact, the Matsumoto thresholds clearly follow the OHC threshold down to the frequency below which the two diverge. The Matsumoto thresholds are lower than the OHC thresholds at frequencies below the point at which they diverge.

These studies and more recent studies demonstrate that wind turbines (specifically wind turbine-generated ILFN) have the potential to not only annoy humans, but harm them physiologically.

The data presented herein represent the conditions of measurement during the study and do not necessarily represent maximum noise conditions produced by the Kumeyaay and Ocotillo facilities. Higher wind speeds generally produce higher noise levels in particular higher ILFN. This is clearly demonstrated in the Ocotillo data when comparing the daytime and nighttime levels.

INTRODUCTION

As requested, Wilson, Ihrig & Associates (WIA) performed noise measurements in the vicinity of the Kumeyaay Wind Farm, located on the Campo Indian Reservation near Boulevard, California. We also took similar measurements in the vicinity of the Ocotillo Wind Energy Facility located near Ocotillo, California. The purpose of the measurements was to determine whether, and at what levels and under what conditions, the Kumeyaay Wind and Ocotillo Wind turbines generate ILFN[6], and how far the ILFN is propagated. A subsidiary goal was to accurately show the pressure fluctuations in the sound, so as to allow an accurate and robust analysis of the human health and other environmental impacts of the ILFN generated.

Between April 28 and April 30, 2013, we recorded noise samples at numerous residential and reference locations near each wind turbine facility. The wind turbines at both facilities were operating the entire time during which we took our noise measurements. Although it would have been our preference to also measure ambient noise conditions with all wind turbines taken out of operation, turbine operation was out of our control. In any event, even without measurements of the ambient noise sans wind turbines, we successfully measured and isolated wind turbine-generated noise.

Through a spectral analysis of the noise recordings, we obtained sound pressure level data demonstrative of the wind turbine-generated ILFN. In this report, we discuss the manner in which the data were obtained and present and analyze the study results.

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[5] Yasunao Matsumoto, et al, An investigation of the perception thresholds of band-limited low frequency noises; influence of bandwith, published in The Effects of Low-Frequency Noise and Vibration on People, Multi-Science Publishing Co. Ltd.

[6] Infrasound is defined as sound at frequencies less than 20 Hz. The focus of this report is frequencies less than 40 Hz, which includes low frequency sound as well.

WIND TURBINE DETAILS

Kumeyaay Wind Farm

Kumeyaay Wind is owned by Infigen Energy of Australia and operated by Bluarc Management of Texas, on 45 acres of land on the Campo Indian Reservation in southeastern San Diego County.[7] The nearest community outside of the tribal land is Boulevard, California. Currently there are 25 wind turbines operating at this facility. The wind turbines are located on a north-south ridge (Tecate Divide) at elevations ranging from 4,200 to 4,600 feet. The turbines started generating power in December 2005.

Kumeyaay Wind's turbines are Gamesa model G87X-2.0, with a rated power of 2.0 megawatts (MW). According to the manufacturer's published data, the G87X-2.0 has a hub height (height of the nacelle, which houses the gearbox, transmission and generator) that can vary from 217 to 325 feet depending on site conditions. The manufacturer also represents that the turbine has a rotor diameter of 283 feet, with three 138-foot-long, adjustable pitch blades. According to Councilman Miskwish the hub height of the Kumeyaay Wind turbines is typically 228 feet, and the blades are 145 feet long. Figure 1 shows some of the wind turbines.

The G87-2.0 model has a reported cut-in wind speed of 8.9 mph (5 mph according to former Campo tribal Councilman Miskwish, a.k.a. Michael Connolly) and achieves its rated (max) power generation at about 31 mph. The operational speed of the turbines is reported by the manufacturer to be in the range of 9 to 19 revolutions per minute (rpm) depending on wind conditions.

Figure 1 Wind Turbines at Kumeyaay Wind

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7 "Kumeyaay Wind Energy Project," PowerPoint presentation by Councilman Michael Connolly Miskwish, Campo Kumeyaay Nation, November 30, 2008., *available here:* http://www.certredearth.com/pdfs/Presentations/2007/KumeyaayWindEnergyProjectCampoKumeyaayNation.pdf

Ocotillo Wind Energy Facility

The Ocotillo Wind facility is owned and operated by Pattern Energy, on 10,200 acres of federal land located in southwestern Imperial County and managed by the United States Bureau of Land Management (BLM). Ocotillo Wind currently has 112 operating wind turbines. The wind turbines are located on the desert floor adjacent to the community of Ocotillo, California, at elevations ranging from approximately 300 to 1,400 feet above sea level. The Ocotillo Wind turbines are Siemens model SWT-2.3-108, with a rated power of 2.3 MW. Figure 2 shows some of Ocotillo Wind's turbines.

According to the manufacturer's published data, the SWT-2.3-108 model has a nominal hub height of 260 feet depending on site conditions, with a turbine rotor diameter of 351 feet and three 172-foot-long blades. The SWT-2.3-108 has a manufacturer-reported cut-in wind speed between 6.6 and 8.9 mph and achieves its rated power at wind speeds between 24 and 27 mph. The operational speed of the turbines reported by the manufacturer is in the range of 6 to 16 rpm depending on wind conditions.

Figure 2 Wind Turbines at Ocotillo Wind

MEASUREMENT LOCATIONS

Kumeyaay Wind-Area Residences

Both indoor and outdoor noise recordings were made at six residences in the Boulevard area near the Kumeyaay Wind turbines.

Table 1 lists the addresses of the residences at which the measurements were taken, along with the dates and times of the recordings. A map showing the Kumeyaay Wind-area measurement locations is provided in Appendix A.

Table 1 Addresses of Residences Used in Kumeyaay Measurements

Resident/Owner	Address	Distance to Closest Wind Turbine	Date	Recording Start Time	Recording End Time[1]
D. Elliott	Off of Crestwood, Campo Indian Reservation	2,960 feet	April 28	16:02	16:22
			April 30	11:00	11:20
G. Thompson	33 Blackwood Road, Manzanita Indian Reservation	2,880 feet	April 28	18:47	19:07
R. Elliott	25 Crestwood Road, Manzanita Indian Reservation	4,330 feet	April 28	17:30	17:50
D. Bonfiglio	40123 Ribbonwood Road, Boulevard	2.9 miles	April 29	9:15	9:35
K. Oppenheimer	39544 Clements Street, Boulevard	1.6 miles	April 30	15:11	15:31
M. Morgan	2912 Ribbonwood Road, Boulevard	1.7 miles	April 30	16:15	16:35
D. Tisdale	Morning Star Ranch, San Diego Co.	5.7 miles	April 30	13:45	14:05

[1] Recordings were nominally 20 minutes long

The Kumeyaay Wind-area residences at which we took measurements are located at distances of 2,880 feet to 5.7 miles from the nearest wind turbine at Kumeyaay Wind Farm. Additional recordings were made at two reference locations, which were closer to the wind turbines than the residential locations, as shown below in Table 2.

A recording was also obtained at the Tisdale ranch located 5.7 miles from the nearest wind turbine (see Table 1 above). The purpose of this recording was primarily to document existing ambient conditions; however, even at that great distance, analysis of the data indicates the presence of noise generated by the existing turbines.

A recording was also made at one of the guest cabins at the Live Oak Springs Resort. The purpose of this latter measurement was to obtain noise recordings in a condition with essentially no "local wind." By no local wind, it is meant that the wind at the microphone was either very light or non-existent even though there was wind at the wind turbine level, which was confirmed by observing the closest wind turbine rotating, thus providing a sample of wind turbine noise that was minimally affected by wind on the microphone. This latter recording was made at 10:10 pm on April 28. Cabin #2 at Live Oak Springs Resort is 5,950 feet from the nearest wind turbine.

Kumeyaay Reference Noise Measurements

To more fully document wind turbine-generated noise levels and spectra, we took noise measurements at locations closer to the subject wind turbines than the residences used in this study. Two reference locations were used near Kumeyaay Wind. Table 2 indicates the locations, distances to the closest wind turbine, dates and times of the reference recordings.

Table 2 Reference Locations for Kumeyaay Wind

Location	Distance to Closest Wind Turbine (feet)	Date	Recording Start Time	Recording End Time[1]
Kumeyaay (K-R1)	2,040	April 28	15:58	16:18
Kumeyaay (K-R2)	930	April 30	11:00	11:20

[1] Recordings were nominally 20 minutes long

The recording on April 28 at 10:00 pm at Live Oak Springs Resort (K-LOSR) also serves as a reference measurement.

Ocotillo Wind-Area Residences

Recordings were made at three Ocotillo residences near the Ocotillo Wind turbines. Table 3 lists the addresses of the residences at which the measurements were taken, along with the dates and times of recordings. A map showing the Ocotillo Wind-area measurement locations is provided in Appendix A.

Table 3 Addresses of Residences Used in Ocotillo Measurements

Resident/Owner	Address	Distance to Closest Wind Turbine	Date	Recording Start Time	Recording End Time[1]
J. Pelly	1362 Shell Canyon Road, Imperial County	3,220 feet	April 29	11:22	11:42
				20:00	20:20
P. Ewing	98 Imperial Highway, Ocotillo	3,590 feet	April 29	12:32	12:52
				21:00	21:20

D. Tucker	1164 Seminole Avenue, Ocotillo	1.2 miles	April 29	13:42	14:02
				22:20	22:40

[1] Recordings were nominally 20 minutes long

The Ocotillo Wind-area residences at which we took measurements are located at distances of 3,220 feet to 1.2 miles from the closest wind turbine at Ocotillo Wind. We also made measurements at three reference locations closer to the wind turbines, as shown in Table 4 below.

Ocotillo Reference Noise Measurements

We used three reference locations near Ocotillo Wind. Table 4 lists the locations, distance to the closest wind turbine, dates and times of the reference recordings.

Table 4 Reference Locations for Ocotillo

Location	**Distance to Closest Wind Turbine (feet)**	**Date**	**Recording Start Time**	**Recording End Time**[1]
Ocotillo (O-R1)	1,540	April 29	11:19	11:39
			20:00	20:20
Ocotillo (O-R2)	1,470	April 29	13:44	14:04
			21:30	21:50
Ocotillo (O-R3)	2,100	April 29	22:08	22:28

[1] Recordings were nominally 20 minutes long

NOISE RECORDING METHODOLOGY

We made all of the noise recordings with Brüel and Kjaer (B&K) type-4193, ½-inch, pressure-field microphones, which are specifically designed for infrasound measurement and provide a linear response from 0.07 cycles per second (Hz) to 20,000 Hz. A B&K type-UC-0211 adapter was used to couple the microphones to a B&K type-2639 preamplifier, providing a linear frequency response down to 0.1 Hz for the microphone/adaptor/preamplifier system. All recordings were calibrated with B&K type-4230 calibrators, which are checked and adjusted with NIST traceable accuracy with a B&K type-4220 pistonphone in the WIA laboratory in Emeryville, California.

We recorded all the noise samples with a TEAC LX10, 16-channel digital recorder, which provides a linear frequency response (i.e., ±0.1% or less) to a lower frequency limit of essentially 0.1 Hz when used in the "AC mode" (which we did). Twenty minute (nominal) noise recordings were made at each location. Using two different microphones, recordings were made simultaneously both indoors and outdoors at each subject residence. This same approach was also used in the Shirley Wind Farm study[8].

Using a third microphone and another recorder (SONY PCM D-50 digital recorder), recordings were made at reference locations closer to the wind turbines while the residential recordings were in progress. The frequency response of this third system is linear down to a frequency of 1.4 Hz, being limited by the SONY recorder.

For several of the residential and reference locations, recordings were repeated at a different time and/or date. All measurement data reported herein are based on an analysis of the noise recordings played back in the WIA laboratory.

Residence Location Measurements

For measurements conducted at the residences, a microphone was set up inside each residence mounted on a tripod at 4.5 feet above the floor, typically in the middle of the room. The indoor recordings were made in either the living room (mostly) or dining room of the residences. Indoors, the microphone was oriented vertically and covered with a 7-inch-diameter wind screen. Figure 3 shows the microphone and windscreen mounted on a tripod inside one of the residences.

A second microphone was set up outside of each residence. Following IEC Standard 61400-11, the outside microphone was rested horizontally (i.e., flush mounted) on a ½-inch-thick plywood "ground board" that is 1 meter in diameter. The microphone was oriented in the direction of the nearest visible wind turbine and the ground board was placed in a flat location between the residence and the wind turbines.

Also following IEC 61400-11, wind effects on the outdoor microphone were reduced using both a hemispherical 7-inch-diameter primary windscreen placed directly over the microphone, and a hemispherical 20-inch-diameter secondary windscreen placed over the primary windscreen and mounted on the ground board. The microphone and primary windscreen were placed under the center of the secondary windscreen.

The primary windscreen was cut from a spherical, ACO-Pacific foam windscreen with a density of 80 pores per inch (ppi). The secondary windscreen was constructed by WIA using a wire frame covered with ½ inch open wire mesh. A one-inch-thick layer of open cell foam with a density of 30 ppi was attached to the wire mesh. Figure 4 shows the outdoor microphone, secondary windscreen, and ground board outside one of the residences.

Both microphones used at the residences were powered by B&K type-2804 power supplies, with signals amplified by a WIA type-228 multi-channel measurement amplifier, and recorded on a TEAC LX10 16-channel digital data recorder. Inside and outside noise signals were recorded simultaneously to allow for correlation of interior and exterior sound levels during analysis.

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[8] Channel Islands Acoustics, et al, A Cooperative Measurement Survey and Analysis of Low Frequency and Infrasound at the Shirley Wind Farm in Brown County, Wisconsin, Report No. 122412-1, December 24, 2012.

Figure 3 Microphone Inside Residence

Figure 4 Microphone Outside Residence

Reference Location Measurements

A third B&K 4193 microphone was used to obtain simultaneous reference measurements at locations closer to the wind turbines during each of the residential measurements. This third microphone was powered by a B&K type-5935 power supply and amplifier, with the signal recorded on a Sony type PCM D-50 recorder. The same windscreen and ground board configuration (i.e., primary and secondary windscreen) used for the residential recordings, was also used for the reference locations. Reference measurements were obtained at different locations at each of the two facilities. Figure 5 shows the microphone, ground board and secondary windscreen at one of the reference measurement locations in Ocotillo.

Figure 5 Reference Location O-R2 with Microphone, Ground Board and Windscreen

NOISE MEASUREMENT BACKGROUND

Purpose of Measurements

The primary purpose of making the wind turbine noise measurements reported herein was to determine whether, and at what levels and under what conditions, the Kumeyaay Wind and Ocotillo Wind turbines generate ILFN, and how far the ILFN is propagated. In light of increasing evidence in the literature that ILFN can affect and harm humans[9] [10] [11] [12] [13], along with numerous complaints of health impacts from both Boulevard- and Ocotillo-area residents[14] since the wind turbines near their respective residences began operating, we had a subsidiary goal to obtain measurements that accurately show the pressure fluctuations in the sound, so as to allow an accurate and robust analysis of the human health and environmental impacts of the ILFN generated.

Noise Measurements in Presence of Wind

Some atmospheric pressure fluctuations are oscillatory in nature, whereas others are not. An example of a non-oscillatory pressure fluctuation is a change in barometric pressure; a change that occurs over a much longer time scale (e.g., hours) than the fluctuations being measured in this study. Wind and, in particular, gusts of wind cause another form of non-oscillatory pressure fluctuation, though it occurs on a much shorter time scale (e.g., fraction of a second). Local wind can cause a pressure change affecting the human ear similar to the pressure change that occurs in an airplane as it ascends or descends during takeoff and landing, but this pressure change is not sound.

Sound, in contrast to non-oscillatory fluctuations, consists of regular oscillatory pressure fluctuations in the air due to traveling waves. Sound waves can propagate over long distances depending on many factors. In the case of noise generated by machinery, the pressure fluctuations can be highly periodic in nature (i.e., regular oscillations). Sound that is characterized by discrete frequencies is referred to as being tonal. Although wind can generate sound due to turbulence around objects (e.g., trees, buildings), this sound is generally random in nature, lacks periodicity and is usually not in the infrasound range of frequencies.

However, the sound measurements we were interested in for this study (i.e. periodic wind turbine-generated ILFN) can be greatly impacted by non-oscillatory pressure fluctuations and extraneous noise caused by, for example, wind turbulence due to steady wind and particularly during gusts. The microphones we used in these measurements are highly sensitive instruments, with pressure sensor diaphragms that will respond to any rapid enough pressure change in the air regardless of the cause. To minimize the artificial (i.e. unrelated to the noise source being measured) noise or "pseudo sound" caused by wind gusts and other pressure fluctuations not associated with the wind turbine-generated noise itself, we employed special procedures. The

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[9] Salt, A.N., T.E. Hullar, Responses of the ear to low frequency sounds, infrasound and wind turbines, Hearing Research, 16 June 2010.

[10] Salt, A.N., J.T. Lichtenhan, Reponses of the Inner Ear to Infrasound, Fourth International Meeting on Wind Turbine Noise, Rome, Italy, April 2011.

[11] Salt, A.N., J.A. Kaltenbach, Infrasound from Wind Turbines Could Affect Humans, Bulletin of Science, Technology & Society, 31, 296-302, 2011.

[12] Salt, A.N., J.T. Lichtenhan, Perception-based protection from low-frequency sounds may not be enough, Inter-Noise 2012, New York, New York, August 2012.

[13] Lichtenhan, J.T., A.N. Salt, Amplitude Modulation of Audible Sounds by Non-Audible Sounds: Understanding the Effects of Wind-Turbine Noise, Proceedings of JASA, 2013.

[14] San Diego Reader, Volume 42, Number 34, August 22, 2013.

main sources of artificial noise and the procedures we used to minimize its impact are discussed more fully below.

Artificial Noise due to Turbulence at the Microphone

One source of artificial noise caused by wind on the microphone – and the most commonly encountered artificial noise source in outdoor noise measurements – is the turbulence caused by wind blowing over the microphone. To minimize this effect of wind when conducting environmental noise measurements outdoors, it is standard practice to use a windscreen,[15] the size of which is usually selected based on the magnitude of the wind encountered. The higher the wind speed generally the larger the windscreen required to minimize artificial noise caused by air turbulence at the microphone.

The windscreen used must be porous enough so as not to significantly diminish the pressure fluctuations associated with the noise being measured, which is to say that the wind screen must be acoustically transparent. As indicated above, the measurements reported herein followed procedures on windscreen design and usage as recommended by IEC 64100-11.

Artificial Noise due to Air Gusts

There is another – and more problematic – source of artificial wind-based noise. This one is caused by non-oscillatory pressure fluctuations associated with wind gusts as well as the pressure associated with the air flow in a steady wind. Air gusts can have an effect on a microphone signal in two ways. Outdoors, the microphone diaphragm will respond to the direct change in pressure associated with air flow; whereas indoors, the microphone will respond to the indirect change in pressure associated with wind and particularly gusts of wind that pressurize the interior of the building. These wind effects induce artificial noise that appears in the electrical signal generated by the microphone that is in the ILFN frequency range. This pseudo noise can, in turn, affect the spectral analysis of the recorded data. This form of pseudo noise (i.e., pressure changes due to air flow) is not substantially reduced by the use of a windscreen or even multiple windscreens generally regardless of their size.

Here, as discussed more fully in the Method of Analysis of Recorded Data section below, we analyzed the sound recordings in this study using a fast Fourier transform (FFT) technique to resolve low frequency and infrasound data. The primary range of interest in these measurements was in frequencies between 0.1 and 40 Hz. An FFT analysis produces a constant bandwidth (B). A 400-line FFT was used in the analysis, which means the bandwidth was B = 0.1 Hz. This allows resolution of frequency components to fractions of one Hz.

When using a very narrow bandwidth (e.g., 0.1 Hz), the time required for filtering is long in order to obtain the frequency resolution. The FFT analysis time T required for a specific bandwith B is given by: $T = 1/B$. For a 0.1 Hz bandwidth the time required is 10 sec. At this time scale, the effects of air pressure changes due to air movement tend to linger in the filtering process as discussed in the Method of Analysis of Recorded Data section below.

[15] ANSI S12.9-2013/Part 3, Quantities and Procedures for Description and Measurement of Environmental Sound, Part 3: Short-Term Measurements with an Observer Present, American National Standards Institute, 2013.

To reduce the wind gust-induced artificial noise that manifests in the data with such long filtering times, both physical means during recording and analytical post-recording methods can be employed to minimize this artificial noise. The most effective pre-measurement technique is to dig a hole in the ground and put the microphone into it.[16] If two pits and microphones are used, then a cross-spectral analysis is also possible. In this study, however, it was impractical and, in some cases, impossible to dig microphone pits at the 15 total measurement locations. We thus relied on post-measurement analytical methods to filter out the pseudo noise as much as possible.

Each of the two most effective analytical techniques takes advantage of the fact that wind turbines and other large rotating machinery with blades (e.g., building ventilation fans and helicopters) produce very regular, oscillatory pressure fluctuations that are highly deterministic,[17] whereas pressure changes due to air movement associated with local wind gusts are essentially random in nature. The sound produced by wind turbines is tonal in nature, meaning that it has a spectrum with discrete frequencies that, in this case, are interrelated (i.e., harmonics of the blade passage frequency). This difference between the random wind noise and the wind turbine noise provides a means to minimize the latter in the signal processing of the recorded data. It has been posited that it is the tonal nature of wind turbine infrasound that may have some influence on residents in the vicinity of large wind turbines[18].

The artificial noise associated with pressure changes at the microphone due to local wind gusts can be minimized in two ways when analyzing the recorded signal. The first technique is to average the noise measurements over a longer time period. This tends to reduce the effect of pseudo noise associated with random air pressure transients during wind gusts, but does not affect the very regular, periodic pressure fluctuations generated by wind turbines.

When averaging over time is not sufficient, a second technique can be used to further minimize the effect of random pressure fluctuations associated with local wind. This second technique uses “coherent output power,” a cross-spectral process. Both time averaging and coherent output power are discussed below under the method of analysis of recorded data.

WIND TURBINE OPERATION DURING MEASUREMENTS

Video recordings were made several times during the study period to document the operation of the wind turbines. Using the video recordings, we determined both the rotational speed of the wind turbine rotors (Ω in rpm) and the so-called “blade passage frequency” (f_0, also referred to as “blade passing frequency” or BPF), which is calculated in cycles per second, where $f_0 = N \times \Omega / 60$, and N is the number of blades. For a three-bladed rotor ($N = 3$) the blade passage frequency is given by the equation:

[16] Betke, L. and H. Remmers, Messung and Bewertung von tieffrequentem Schall, Proceedings of DAGA 1998 (in German)

[17] Johnson, Wayne, Helicopter Theory, Dover Publications, New York, 1980.

[18] Hessler, G., P. Schomer, Criteria for Wind-turbine Noise Immissions, Proceedings of the Meetings on Acoustics ICA 2013, Montreal, 2-7 June 2013, Acoustical Society of America, Vol. 19, 040152 (2013).

$$f_0 = \frac{\Omega}{20} .$$

Associated with the blade passage frequency are harmonics, which are integer multiples of the blade passage frequency. In this study, we typically observed at least five discrete harmonics in the measurement data. This pattern was also observed in the aforementioned Shirley Wind Farm study.

The harmonic frequencies are given by:

$$f_n = (n + 1) \times f_0 , where\ n \geq 1 .$$

For example, if Ω = 17 rpm, then f_0 = 0.85 Hz and the frequencies of the first six harmonics (n = 1 through 6) are: 1.7, 2.6, 3.4, 4.3, 5.1 and 6.0 Hz.

Table 5 summarizes a selection of the wind turbine speeds observed during the recordings. We note that the turbine speed of 16.2 rpm observed in Ocotillo at 19:51 on April 29 is the maximum rated speed for the Siemens SWT-2.3-108.

Table 5 Rotational Speeds Observed for Nearest Wind Turbines

Facility	**Date**	**Location**[1]	**Time**	**Speed (rpm)**	**BPF (Hz)**
Kumeyaay Wind (Gamesa Turbines – rated speed of 9 to 19 rpm)	April 28	D. Elliott	14:14	17.3	0.87
			15:05	17.1	0.86
			16:29	16.8	0.84
			16:30	16.3	0.81
		R. Elliott	17:28	16.7	0.83
		Thompson	19:32	17.2	0.86
Kumeyaay Wind (Gamesa Turbines – rated speed of 9 to 19 rpm)	April 29	Bonfiglio	9.37	12.2	0.61

Ocotillo Wind (Siemens Turbines – rated speed of 6 to 16 rpm)	April 29	O-R1	11:26	9.8	0.49
			11:29	7.4	0.37
			11:32	6.5	0.32
		O-R2	12:40	13.3	0.67
			13:54	15.0	0.75
			14:02	12.5	0.63
		O-R1	19:51	16.2	0.81
Kumeyaay Wind (Gamesa Turbines – rated speed of 9 to 19 rpm)	April 30	D. Elliott	10:33	15.6	0.78
		K-R2	11:22	16.7	0.83
			11:24	13.6	0.68
		Tisdale	13:45	14 to 16.6[2]	0.7 to 0.83[2]
		Oppenheimer	14:50	16.7	0.83
			15:17	17.1	0.86
			15:27	16.7	0.83
		Morgan	16:12	17.1	0.86
			16:18	16.2	0.81
			16:28	17.1	0.86

[1] Locations refer to where video was recorded

[2] Based on observed rotor speeds before and after recording

METEOROLOGICAL DATA

Weather Underground provides publicly available weather data for the two measurement areas (Boulevard and Ocotillo) on its website (wunderground.com). Among other things, this data includes wind speed, wind direction, temperature, and pressure. Weather Underground reports that it measures the meteorological conditions for Boulevard and Ocotillo at respective elevations of 4,113 feet and 694 feet above sea level. The relevant Weather Underground weather data for the Boulevard and Ocotillo areas is provided in Appendix B and summarized below.

Meteorological Data for the Kumeyaay Wind-Area Noise Measurements

We obtained noise measurements in the vicinity of the Kumeyaay Wind turbines on two different days. We took measurements on April 28, 2013, in the mid-afternoon to early evening. On April 30, we took measurements from mid-morning to mid-afternoon.

April 28, 2013

The Weather Underground data for this date show wind from the northwest in the morning, shifting to the west in the afternoon when the noise recordings were made. Average wind speeds between 1pm and 7pm were approximately 15 mph, with some gusts reaching 25 mph.

April 29, 2013

The Weather Underground data for this date show that wind speeds were considerably lower than on April 28, typically averaging between 5 and 8 mph, with some gusts reaching 10 mph. The wind direction between 9 am and 10 am, when the lone Kumeyaay Wind-area noise recording on this date was made, was from west south west.

April 30, 2013

The Weather Underground data for this date show that the wind direction in the morning was from the west, with average wind speeds that were 5 mph or less during the second recording at Mr. Elliott's residence. In the afternoon, during recordings at the Oppenheimer, Morgan and Tisdale residences, the wind was from the southwest, with average wind speeds between 10 and 17 mph and gusts up to 25 mph.

Meteorological Data for the Ocotillo Wind-Area Noise Measurements

We took noise measurements only on April 29, 2013, for the Ocotillo Wind Energy Facility. We took measurements from mid-morning to mid-afternoon, and then again from early evening to late evening.

April 29, 2013

The Weather Underground data for this date show that between 11am and 2 pm the wind direction was from the southwest with average wind speeds between 10 and 15 mph, with gusts from 15 to 20 mph. In the evening, the wind was also from the southwest, but was much stronger, with average wind speeds between 15 and 25 mph and gusts up to 35 mph.

METHOD OF ANALYSIS OF RECORDED DATA

We analyzed the 20 minute (nominal) recordings in the WIA laboratory with a Larson Davis type-2900 2-channel FFT analyzer. We first viewed each recorded sample in digital strip chart format to visually locate periods of lower local wind gusts to minimize low-frequency wind pressure transient effects on the data. We set the FFT analyzer for 40-Hz bandwidth, with 400-line and 0.1-Hz resolution. We used linear averaging. A Hanning window was used during a one- to two-minute, low-wind period to obtain an "energy average" with maximum sampling overlap. We stored the results for each sample, including autospectra, coherence, and coherent output power for both channels of data at the residential locations (i.e., indoors and outdoors). We also obtained autospectra for the reference locations.

Autospectra and Coherent Output Power

One of the strengths of our indoor-outdoor sampling design is that it made possible the use of what is called the "coherent output power" to filter out of the data the effect of the low-frequency wind pressure transients caused by local wind gusts. If two closely correlated signals are available (such as we have here, with the indoor and outdoor measurements for each residential study location), it is possible to use the coherent output power to reduce the effects of uncorrelated or weakly correlated phenomenon associated with wind gusts.

Coherent output power is based on use of the coherence between two signals to weight the spectra of one of the signals based on coherent frequency components common to the two simultaneously recorded signals. Where, as here, the wind turbine-generated noise remains at fairly consistent frequencies over the recording periods, the effects on the recorded signal of the essentially random, non-oscillatory pressure fluctuations caused by wind gusts should be reduced using this analysis procedure. The result is sometimes referred to as the coherent output spectrum.[19] For an example of previous studies that have used coherent output power to obtain wind turbine noise spectra, see Kelley, et al. (1985).[20]

In discussing coherent output power we use standard signal processing terminology. Obviously, all of the terms are functions of frequency.

For two signals (signal 1 and signal 2), the coherent output power for signal 2 (i.e., G_2) is defined as:

$$G_2 = {\gamma_{12}}^2 G_{22} \; .$$

The term ${\gamma_{12}}^2$ is the coherence (also referred to as spectral coherence) between the two signals and the term $G_{22}$is the autospectral density of the second signal. The value of the coherence lies in the range of $0 \le {\gamma_{12}}^2 \le 1$. A value of ${\gamma_{12}}^2 = 1$ indicates there is a one-to-one correlation between the two signals, which could only occur within an ideal system. In practice, ${\gamma_{12}}^2$ will generally be less than 1.

The coherence is defined as:

$${\gamma_{12}}^2 = \frac{|G_{12}|^2}{G_{11} G_{22}}$$

The term autospectral density used here has the same meaning as sound pressure level spectrum, the units of which are dB (re: 20 µPa). The term G_{11} is the autospectral density of the first signal.

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[19] Bendat, J. and A. Piersol, Random Data – Analysis and Measurement Procedures, 2nd Edition, John Wiley & Sons, 1986.

[20] Kelley, N.D., et al., Acoustic Noise Associated with the MOD-1 Wind Turbine: Its Source, Impact and Control, SERI/TR-635-1166 report prepared for U.S. Department of Energy, Solar Energy Research Institute, February 1985.

The term G_{12} is the cross-spectral density between the two signals, and the term $|G_{12}|^2$ is the square of the magnitude of the cross-spectral density.

For two recorded signals, it is possible to determine the coherence of the first with respect to the second (γ_{12}) and switch the two and determine the coherence of the second with respect to the first (γ_{21}). Consequently it is possible to obtain an inside coherent output power spectrum and an outdoor coherent output power spectrum. The measurement data presented herein indicate when the data are the autospectra, and when they are determined from the coherent output power. Where coherence data are presented, it is the coherence of the indoor signal with respect to that of the outdoor signal.

Sound Level Corrections Due to Use of Ground Board

Placing an outdoor microphone on a ground board, as was done in this study, results in higher sound pressure levels (up to 3 dB greater) for frequencies in the range of 50 to 20,000 Hz when compared to those measured at 4.5 to 5.5 feet above the ground, a standard height used to make environmental noise measurements as indicated in ANSI S12.9-2013/Part 3. Consequently corrections to the sound level data at frequencies greater than 50 Hz obtained using a ground board would be required.

However, for frequencies less than 50 Hz, the sound pressure level at the ground surface is essentially the same as that at a height of 5 feet. This is because a microphone on a tripod 5 feet above the ground is at a height less than one-fourth the wavelength of the sound at this frequency (i.e., $0.25 \times \lambda_{50\,Hz} = 0.25 \times \frac{1{,}100}{50} = 5.5\, feet$) and there is little difference at frequencies less than 50 Hz between the sound field at ground level and the sound field at 5 feet above the ground. This fact has been confirmed by other measurements[21].

Because the data presented herein are in the ILFN range with frequencies less than 40 Hz, no corrections to the sound level data are necessary, even though the measurements were made with a ground board.

NOISE MEASUREMENT RESULTS

Noise Data for Kumeyaay Wind

The noise spectra data from the Kumeyaay Wind-area measurements are provided in Appendix C. The turbine blade passage frequencies – in the range of 0.7 to 0.9 Hz (see Table 5) – and their harmonics up to 5 Hz are evident in the sound spectra from both recording days. Indeed, they align almost exactly with the predominant spectral peaks. This is a very strong indication that the wind turbines produced the ILFN at those frequencies.

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[21] Hansen, K., Z. Branko, C. Hansen, Evaluation of Secondary Windshield Designs for Outdoor Measurements of Low Frequency Noise and Infrasound, 5th International Conference on Wind Turbine Noise, Denver, 28-30 August 2013.

Data for Live Oak Springs Resort, Cabin #2 (K-LOSR)

It is instructive to first examine the spectra obtained at the Live Oak Springs Resort where there was virtually no local wind during the recording even though there was wind at the turbines as determined from observing the closest turbine rotating at the time. Live Oak Springs Resort is somewhat sheltered from wind, but has a direct line of sight to the closest wind turbine at a distance of 5,950 feet.

Looking at Figure C-1, it is evident in the autospectra for both indoor and outdoor measurements that the discrete frequencies predominating in the infrasound range correspond to the blade passage frequency of the nearest wind turbine (0.8 Hz) and its first five harmonics (1.6, 2.4, 3.2, 4.1 and 4.9 Hz). A blade passage frequency of 0.8 Hz corresponds to a rotational speed of 16 rpm. We note that the indoor levels at these frequencies are slightly higher than the outdoor levels, an indication of possible amplification associated with the building structure.

Figure C-2 presents the two coherent output power spectra and the coherence of the indoor to outdoor signals. At the blade passage frequency (0.8 Hz) and in the range of 1.6 to 5 Hz (including the first five blade passage frequency harmonics of 1.6, 2.4, 3.2, 4.1 and 4.9 Hz), the coherence is 0.75 or greater, indicating a strong correlation between indoor and outdoor sound levels.

A high coherence indicates that two signals are strongly correlated and contain the same frequency content. This is exactly what one would expect from a large rotating mechanical device such as a wind turbine that produces a steady, tonal (periodic) sound, whereas the effects of wind are very random in particular concerning signals from two different microphones, one of which is indoors. Hence, the correlation of the wind effects in the indoor and outdoor signals should be weak for the random effects of the wind. Thus there will be a low coherence associated with the wind and its effects on the two different signals. Averaging the total microphone signal over time and weighting the result by the coherence results in a diminished contribution from the wind, because of the low coherence of the wind effects.

Figure C-3 compares the autospectrum with the coherent output spectrum for the indoors measurement at Live Oak Springs Resort. It shows a very close match over the frequency range of 0.8 to 5 Hz at the discrete frequencies associated with the wind turbine ILFN.

Inside the guest cabin at Live Oak Springs Resort, sound pressure levels in the infrasound range measured between 45 and 49 dB. The outside sound pressure levels were somewhat lower in the ILFN range, seeming to indicate an amplification occurring from outside to inside, which became even more pronounced in the range of 5 to 8 Hz. There is also a strong peak at 26.4 Hz, which may be caused by an "amplitude modulation" similar to that identified in the Falmouth wind turbine study[22]. The coherence at this frequency is 0.95. Amplitude modulation occurs when a low frequency signal causes the level of a higher frequency signal to fluctuate. This fluctuation occurs at the frequency of the lower frequency signal. This has been the subject of many complaints concerning wind turbine noise[23] [24].

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[22] Ambrose, S. and R. Rand, The Bruce McPherson Infrasound and Low Frequency Noise Study, 14 December 2011.

[23] Gabriel, J., S. Vogl, T. Neumann, Amplitude Modulation and Complaints about Wind Turbine Noise, 5th International Conference on Wind Turbine Noise, Denver, 28-30 August 2013.

The ILFN levels at Live Oak Springs Resort's guest Cabin #2 would have been even greater if the cabin were closer to the nearest Kumeyaay Wind turbine than it is – 1.1 miles, or 5,950 feet. The ILFN levels would have also been greater under different wind conditions. According to the Weather Underground report for Boulevard, at the time we measured the noise at the guest cabin – starting at 10:10 pm on April 28 – the wind was blowing from the west with an average speed of approximately 7 mph and gusts up to 12 mph, which is at the lower end of the operating conditions for the Gamesa wind turbines. Because the closest wind turbine is north-northeast of the cabin, the cabin was crosswind and somewhat upwind of the turbine and thus receiving lower levels of turbine-generated noise than locations downwind of the turbines.

Data for Dave Elliott's Residence

Like the Live Oak Springs Resort guest cabin measurements, the April 30 (11 am) measurements at Dave Elliott's residence show pronounced peaks in the autospectra at frequencies corresponding to the blade passage frequency of the nearest wind turbine (0.78 Hz) and the first five harmonics. The inside level at 0.78 Hz was 54 dB. In this case, as displayed in Figure C-4, the sound levels were slightly higher inside than outside at 1.6 and 2.4 Hz. Above 3 Hz the inside levels were lower than outside. The maximum inside sound level of 59 dB occurred at 1.6 Hz (the first harmonic of the blade passage frequency).

Data for Ginger Thompson's Residence

As shown in the autospectrum in Figure C-5, the April 28 (6:50 pm) measurements at Ginger Thompson's residence demonstrate a similar discrete frequency pattern between 0 and 5.2 Hz that corresponds to the blade passage frequency of the nearest turbine (0.80 Hz) and the first three associated harmonics (1.6, 2.4, and 3.2 Hz), which corresponds to a rotational speed of 16.0 rpm. The lowest frequency peak in the spectrum occurs somewhat lower (i.e., at 0.78 Hz) than the blade passage frequency; a phenomenon seen in some of the other measurement data.

As also seen at Mr. Elliott's residence and at most other study sites, the measured ILFN levels at Ms. Thompson's residence were amplified indoors, with the inside levels higher than outside levels throughout the frequency range. The maximum inside sound level of 60 dB occurred at just below the blade passage frequency of 0.80 Hz.

Data for Rowena Elliott's Residence

In the April 28 (5:30 pm) measurement data from Rowena Elliott's residence, shown in Figure C-6, the autospectra peaks corresponding to WT infrasound from Kumeyaay protrude above the general wind noise spectrum. The inside coherent output power spectrum is also plotted in Figure C-6 with most of the same peaks that appear in the autospectrum. Also present in the spectrum is a peak at 1.0 Hz, which does not correspond to any of the harmonics of the BPF observed in Kumeyaay at that time. We suspect that this infrasound is coming from the wind turbines at Ocotillo Wind, which are 15 to 20 miles away. This peak would correspond to a BPF

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[24] Stigwood, M., S. Large, D. Stigwood, Audible Amplitude Modulation – Results of Field Measurements and Investigations Compared to Psycho-acoustical Assessment and Theoretical Research, 5th International Conference on Wind Turbine Noise, Denver, 28-30 August 2013.

of 0.5 Hz, which would be consistent with the somewhat slower rotational speeds for the WTs in Ocotillo. Detecting WT infrasound from 15 to 20 miles away is not surprising. Metelka[25] for example has measured WT infrasound at a distance of 77 miles from its source. The maximum inside sound level of 53 dB occurred at 1.6 Hz, the first harmonic of the Kumeyaay BPF (0.8 Hz).

Data for Kenny Oppenheimer's Residence

As with the data for the previously discussed measurement locations, the April 30 (3:11 pm) measurement data for Kenny Oppenheimer's residence, shown in Figure C- 7, reveal sound pressure level peaks at the blade passage frequency of the nearest wind turbine (0.9 Hz) and its first three harmonics (1.8, 2.7 and 3.6 Hz). There is also a strong peak both indoors and outdoors at 13.6 Hz whose source, in contrast to the wind turbine-generated ILFN peaks at the blade passage frequency and its first three harmonics, we have been unable to identify. In this case, however, the outside sound levels were much greater than those inside the residence. The highest outside sound level was 57 dB and occurred at the blade passage frequency of 0.9 Hz. By contrast, the highest indoor sound level in the coherent output power spectrum was 44 dB, also at 0.9 Hz.

We have estimated the WT infrasound inside at 0.9 Hz to be approximately 51 dB using the coherent output power spectrum level and correcting for the coherence at that frequency. This seems to indicate that the residence is attenuating the wind turbine infrasound more substantially than at some of the other residences investigated, which could be due to a much more tightly sealed building envelope and/or a more substantial exterior wall construction. This effect was also evident in the data for one of the Ocotillo residences.

As a result of this disparity, the coherence of the indoor and outdoor ILFN signals is not as great as with closer measurement locations, including the Live Oak Springs Resort guest cabin and the residences of Mr. Elliott, Ms. Thompson and Ms. Elliott. Nonetheless, the coherence of the two signals at the blade passage frequency and its first three harmonics is still relatively strong, at 0.5 or greater. This evinces a definite correlation between outdoor and indoor sound levels even at great distance from the wind turbine noise source. Also evident in the data is a peak at 13.7 Hz. The may be caused by amplitude modulation.

Data from Marie Morgan's Residence

The April 30 (4:20 pm) measurement data from Marie Morgan's residence, including the inside and outside coherent output power spectra, are shown in Figure C-8. Like the data measured at the residences of Mr. Elliott, and Ms. Thompson, the data at Ms. Morgan's residence show higher levels of ILFN indoors than outdoors.

And like the data measured at Ms. Elliott's residences, there appear to be multiple – in this case three – different BPFs in the data. The lowest BPF, similar to the data measured at Ms. Elliott's residence, appears to be infrasound coming from Ocotillo Wind (i.e., BPF1 of 0.39 Hz). Above that frequency there are two BPF which are associated with Kumeyaay WTs. Note that not all

[25] Metelka, A., Narrowband low frequency pressure and vibration inside homes in the proximity to wind farms, presentation at the 166th Meeting: Acoustical Society of America, San Francisco, 4 December 2013.

Kumeyaay WTs could be observed, and it is possible that some could be operating at a speed of 14 rpm and others at a speed of 18 rpm. The two BPF are at 0.68 Hz (BPF2) and 0.88 Hz (BPF3). A peak indoor level of 58 dB at the first harmonic of BPF 3 (1.7 Hz) was measured

In any event, the Morgan residence data demonstrate that under the right weather and topographical conditions, large wind turbines like those used at Kumeyaay Wind can produce high levels of ILFN inside buildings even miles away.

Data from Don Bonfiglio's Residence

As with the other Kumeyaay Wind-area study sites, the measurement data for Don Bonfiglio's residence, shown in Figure C- 9, display sound level peaks at the blade passage frequency of the nearest wind turbine (0.61 Hz) and the first three associated harmonics (1.2, 1.8 and 2.4 Hz). The sound levels, both indoors and outdoors, at these frequencies are in the range of 30 to 42 dB. The maximum inside level is 42 dB at 1.2 Hz (the frequency of the first harmonic of the blade passage frequency – BPF2).

While the coherence between the indoor and outdoor measurements is less than 0.5 at the blade passage frequency and associated harmonics, it is not surprising given the distance to the nearest wind turbine (2.9 miles, which is a greater distance than at any other Kumeyaay Wind-area study site except the Tisdale residence). Propagation effects (e.g., intervening terrain, atmospheric conditions) and interactions between infrasound from different wind turbines result in a more complex sound field at infrasound frequency as the distance increases. The wavelength of sound at 1 Hz is approximately 1,100 feet. At 2.9 miles the site is approximately 14 wavelengths from the sources of infrasound. Hence it is normal to witness declining coherence with increased distance due to this complexity. Also evident in the spectral data is a BPF peak at 0.39 Hz, which is most likely infrasound from Ocotillo Wind. There is also a harmonic at 0.78 Hz associated with the BPF.

Data from Donna Tisdale's Residence

The farthest (from a Kumeyaay Wind turbine) measurements we took were at the residence of Donna Tisdale, which is 5.7 miles from the nearest wind turbine. Yet even at that great distance, the data show as indicated in Figure C-10 peaks at the blade passage frequency (BPF2) of the nearest turbine (0.7 Hz) at Kumeyaay and its associated harmonics, albeit at lower sound pressure levels than observed at the closer study sites. The maximum measured indoor ILFN sound level was 43 dB at 0.7 Hz (the blade passage frequency). There is also a lower BPF at 0.39 Hz, which is most likely infrasound from Ocotillo Wind.

As similarly observed at the Bonfiglio residence, the coherence between the indoor and outdoor measurements at the Tisdale residence is mostly less than 0.5 for frequencies below 10 Hz. As indicated above, given the distance from the Tisdale residence to the nearest wind turbine (5.6 miles), this is not surprising. The Tisdale ranch is approximately 27 wavelengths from the wind turbines. The turbines are not visible from the ranch, because of intervening terrain. However the turbines are visible from some higher elevations of the ranch property.

Data from the Reference Sites

In contrast to the data for the Kumeyaay Wind-area residential measurement sites, the frequency and sound level data we present in the autospectra in Figures C-11 and C-12 for the two reference locations shows the autospectra values rather than the coherent output power. Because there was no option for making indoor sound measurements near the reference locations, we only used a single microphone to take measurements and thus did not measure a coherence or coherent output power. At both reference locations (K-R1 and K-R2), the data show clear sound level peaks at the blade passage frequency of the nearest turbine and the associated harmonics in the 0 to 5 Hz range. At K-R1, the sound levels of the peaks ranged from 53 dB to 60 dB (at the blade passage frequency, 0.84 Hz). At K-R2, which at 930 feet away was the measurement site closest to the Kumeyaay Wind turbines, the sound levels were even greater, between 60 dB and 70 dB for the spectral peaks below 3 Hz.

Tabulated Data

Table 6 lists the Kumeyaay Wind-area residential measurement locations, along with their distance from the nearest wind turbine, the highest measured indoor sound pressure levels, and the frequency of those peak sound pressure levels.

Table 6 Summary of Wind Turbine Noise for Kumeyaay Inside Residences

Residence	**Distance**[1]	**Highest Sound Pressure Spectrum Level Indoors**[2,3,4]	**Frequency (Hz) of Peak Spectrum Level**	**Rotor Rotational Component**
D. Elliott	2,960 feet	59 dB	1.6	1st harmonic
G. Thompson	2,880 feet	60 dB	0.8	BPF
R. Elliott	4,330 feet	53 dB	1.6	1st harmonic
K-LOSR	1.1 miles	48 dB	2.4	2nd harmonic
K. Oppenheimer	1.6 miles	51 dB	0.9	BPF
M. Morgan	1.7 miles	58 dB	1.7	1st harmonic
D. Bonfiglio	2.9 miles	42 dB	1.1	1st harmonic
D. Tisdale	5.7 miles	43 dB	1.4	1st harmonic

[1] Distance from closest wind turbine

[2] Decibels (re: 20 μPa)

[3] All but Live Oak Spring Resort, D. Elliott and G. Thompson data are coherent output power levels

[4] Oppenheimer data are estimated from coherent output power and correction for coherence

We note that while the Morgan residence data appears anomalous when compared with the trend of sound pressure levels as a function of distance from the wind turbines, it is not. Instead, the Morgan residence data demonstrates that under the right weather and topographical conditions, large wind turbines like those used at Kumeyaay Wind can produce high levels of ILFN inside buildings even miles away. It appears that one factor that contributed to the higher infrasound levels at the Morgan residence is the fact that this house was located downwind of multiple turbines, whereas the other residences except for Mr. Elliott's were either upwind of the turbines and/or had a more obscured line-of-sight to the full array of turbines compared to the Morgan's.

Noise Data for Ocotillo Wind

The noise spectra for the Ocotillo Wind-area measurements are displayed in Figures C-13 through C-21 in Appendix C. Table 7, below, summarizes much of the relevant data for the residential measurements.

In contrast to the relatively consistent wind conditions in the Kumeyaay Wind area throughout the measurement periods, the wind at the Ocotillo Wind Energy Facility varied greatly across the measurement periods. During the first recordings on the morning of April 29, the wind was generally light and the turbine blades were rotating slowly (less than 10 rpm). In the afternoon, however, the wind picked up considerably and the rotational speed of the turbine blades increased (e.g. 13 rpm). And later that night, when we took our last measurements, the wind speed had increased even more, causing the turbine blades to rotate even faster (i.e., 16 rpm observed at 7:51 pm just before dark). Between the first measurements in the morning and the last measurements at night, the turbines' average blade passage frequency increased from 0.5 Hz to 0.8 Hz.

The Ocotillo recordings were analyzed several different ways using cross-correlation, longer averaging times and 1/3-octave band filtering among other methods, without significantly changing the results. For the Ocotillo data, the coherence between the indoor and outdoor signals is low (i.e., less than 0.5). This, along with the spectral data, indicates a complex sound field with more than one BPF present, rather than a classical spectrum of tonal components including just one BPF and its harmonics. Note that it was only possible to observe a handful of turbines at a time out of the 112 turbines at Ocotillo Wind. Consequently, the BPF indicated in Table 5 for the Ocotillo recordings represent the BPF of the turbine or turbines closest to the reference location measurements and not the BPF for turbines in the entire facility.[26]

One possible explanation for low coherence is that Ocotillo Wind has so many turbines spread out over such a large area (with accompanying differences in wind speed and direction at each turbine), the ILFN produced by the turbines at Ocotillo has a greater probability of being less strongly synchronized as it is at Kumeyaay, for example, where the turbines are arrayed in a line on a ridge and experience a much more uniform wind configuration (i.e., speed and direction). At Ocotillo, it is much more likely that the wind turbines rotate at different speeds from one another. Thus where a residence or other receptor is exposed to ILFN from more than one

[26] After dark (approximately 8 pm) on 30 April 2013 it was not possible to observe the rotational speed of turbines at Ocotillo Wind. However, it was possible to deduce the rotational speed of the turbines from the measured data.

turbine, which will usually be the case with most Ocotillo-area locations, it will experience a complex sound field with varying tonal components derived not only from the different turbines directly, but also possibly from the interaction of tonal components from a multitude of turbines.

Another possible factor contributing to the lower coherence between outdoor and indoor sound levels at Ocotillo could be that the residential structures alter the frequency of the WT noise just enough as the sound energy passes through them that the sound indoors is at a slightly different frequency than the sound outdoors. Although this effect is not as apparent in the Kumeyaay data, it is possible that the distributed pattern of the Ocotillo wind turbines makes it more apparent here.

Data for the Residential Sites

As evidenced by the data in Table 7 and by comparing the coherent output power spectra from the morning and night measurements at the Pelley residence (Figures C-13 and C-14), as well as the afternoon and night measurements at the Ewing residence (Figures C-15 and C-16), the ILFN sounds pressure level increased substantially as the wind speed picked up and the blade passage frequency of the turbines increased. This indicates not only that the Ocotillo Wind turbines produced much of the measured ILFN, but that the turbines can create very high ILFN sounds levels even at substantial distance. The Tucker residence data are shown in Figures C-17 and C-18.

Looking specifically at the Pelly residence data for the daytime measurement (Figure C-14) it would appear that there are two blade passage frequencies present (0.5 and 0.6 Hz). This is not surprising considering the distribution of turbines over a large area where different turbines see different wind conditions. The spectral peaks above the blade passage frequencies are consistent with this assessment. The two blade passage frequencies indicate corresponding rotational speeds of 10 and 12 rpm.

Two distinct blade passage frequencies (0.68 and 0.88 Hz) are also evident from the nighttime measurements at the Pelley residence. These blade passage frequencies are indicative of rotation speeds of 13.6 and 17.6 rpm respectively. Although the higher rotational speed is slightly above the reported, operational speed range (6 to 16 rpm) for the Siemens turbines, there is no other source for the infrasound in this area. Note that the outdoor coherent output power spectrum is omitted for clarity in Figure C-14.

The spectra from the Ewing residence likewise indicate two different blade passage frequencies during both the day and night. In Figure C-15 we see the same frequency of the second BPF of 0.88 Hz in the daytime data, confirming that in fact this is infrasound from the Ocotillo WTs. The nighttime data at the Ewing residence as shown in Figure C-16 indicates two BPF also (0.39 and 0.49 Hz) and their associated harmonics.

The data for the Tucker residence similarly contain two BPF during the day (0.6 and 0.8 Hz) and two in the nighttime (0.39 and 0.68 Hz), with the lower BPF reflected in the data at the Ewing residence at night.

Whereas the Pelly residence data indicates an amplification of sound level between inside and outside, the data for other two residences indicate the opposite. Apparently the Ewing residence is more tightly sealed. It also seemed to be of a more substantial construction. The Tucker residence data also shows a reduction from outside to inside. An explanation for this effect could be the shielding provided by neighboring structures, which are more closely spaced than at the Pelly residence. The Tucker residence may also be more tightly sealed.

That the Ocotillo Wind turbines generated much of the ILFN measured at the Pelley and Ewing residences is strongly supported by the fact that the recorded data for both residences show sound level peaks at the turbine blade passage frequencies and many of the associated harmonics. The reference location measurement data also demonstrate this pattern, although not as clearly.

Data for the Reference Sites

At reference location 1 for the Ocotillo Wind-area measurements (O-R1), the nighttime ILFN levels were quite high, with multiple peaks above 60 dB including at frequencies that correspond to many of the harmonics of the blade passage frequency of the nearest wind turbine. The overall peak sound level of 74 dB occurred at the blade passage frequency (0.8 Hz). At O-R2, which at 1,470 feet away was the measurement site closest to the Ocotillo Wind turbines, the peak sound level of 78 dB was even greater, and also occurred at the blade passage frequency of 0.8 Hz. Similarly, at O-R3, which was adjacent to the Ocotillo substation, the peak sound level was 77 dB and occurred at the blade passage frequency of 0.8 Hz. These data are shown in Figures C-19 through C-21.

Tabulated Data

Table 7 lists the Ocotillo Wind-area residential measurement locations, along with their distance from the nearest wind turbine, the highest measured indoor sound pressure levels, and the frequency of those peak sound pressure levels. As expected given higher wind speeds at night, nighttime, indoor noise levels range from 15 to 27 dB higher than those measured during the day.

Table 7 Summary of Wind Turbine Noise for Ocotillo Inside Residences

Residence	**Distance**[1]	**Time of Day**	**Highest Sound Pressure Spectrum Level Indoors**[2,3]	**Frequency (Hz) of Spectrum Peak Level**	**Rotor Rotational Component**
Pelley	3,220 feet	Day	42 dB	0.6	BPF2
			49 dB	1.0	1st of BPF1
		Night	67 dB	0.68	BPF1
			69 dB	0.88	BPF2
Ewing	3,590 feet	Day	48 dB	0.59	BPF1
			51 dB	0.88	BPF2
		Night	42 dB	0.39	BPF1

			59 dB	0.78	1st of BPF2
Tucker	1.2 miles	Day	42 dB	0.6	BPF1
			48 dB	0.8	BPF2
		Night	66 dB	0.68	BPF2
			69 dB	1.37	1st of BPF2

[1] Distance from closest wind turbine

[2] Decibels (re: 20 μPa)

[3] All are coherent output power spectrum levels

DISCUSSION OF RESULTS

It is clear from the measured noise data obtained from Kumeyaay and Ocotillo facilities that there is significant wind turbine-generated ILFN. This was to be expected as it has been documented by others such as in the McPherson noise study, the Shirley Wind Turbine study, and by Epsilon Associates.[27] And indeed the measured ILFN levels near Kumeyaay and Ocotillo wind turbine facilities are similar to those measured in previous studies after accounting for the proximity of the measurements to a wind turbine and the total number of the wind turbines in the facility.

Both the McPherson and Shirley wind turbine noise studies were conducted to investigate whether and at what levels the subject wind turbines (the turbines in Falmouth, Massachusetts, and those in the Shirley Wind Project in Brown County, Wisconsin) produce ILFN, and whether that ILFN was contributing to the significant health and other impacts reported by nearby residences. In some cases, the impacts were so severe that residents abandoned their homes. Both studies found high levels of wind turbine-generated ILFN at numerous nearby residences that correlated with residents' reported impacts.

Human health impacts from wind turbines had been reported previously in several countries with large wind facilities in proximity to residences. But these impacts were often attributed to certain individuals' aversion to the presence of a large industrial facility constructed in what was previously a quiet rural setting. Scientific understanding has developed significantly since then.

Recent research and investigations into human response to ILFN have been conducted and seem to provide strong evidence of a cause and effect relationship. In particular the work of Salt, et al.[28] has made a clear case for perception of ILFN below the threshold of hearing as defined by ISO 389-7 which is related to the response of the ear's inner hair cells (IHC). Salt has demonstrated that it is possible for the ears' outer hair cells (OHC) to respond to ILFN at sound

[27] Epsilon Associates, A Study of Low Frequency and Infrasound from Wind Turbines, July 2009.

[28] Alec Salt, and J. Lichtenhan, Perception based protection from low-frequency sounds may not be enough, Internoise 2012, August 2012.

pressure levels that are much lower than the IHC threshold. Salt has reported that ILFN levels (levels commonly generated by wind turbines nearby residences) can cause physiologic changes in the ear.[29] Salt and Kaltenbach "estimated that sound levels of 60 dBG will stimulate the OHC of the human ear."[30]

Furthermore, Matsumoto et al.[31] have demonstrated in a laboratory setting that humans can perceive ILFN at sound pressure levels below the IHC threshold when the noise is a complex spectrum (i.e. contains multiple frequency components). From this laboratory research it was clearly demonstrated that humans can perceive sound pressure levels that are from 10 to 45 decibels (dB) less than the OHC threshold in the ILFN range. In fact, the Matsumoto thresholds clearly follow the OHC threshold down to the frequency below which the two diverge. The Matsumoto thresholds are lower than the OHC thresholds at frequencies below the point at which they diverge.

These studies and more recent studies demonstrate that wind turbines (specifically wind turbine-generated ILFN) have the potential to not only annoy humans, but harm them physiologically.

The data presented herein represent the conditions of measurement during the study and do not necessarily represent maximum noise conditions produced by the Kumeyaay and Ocotillo facilities. Higher wind speeds generally produce higher noise levels in particular higher ILFN. This is clearly demonstrated in the Ocotillo data when comparing the daytime and nighttime levels.

NOISE METRICS FOR MEASURING ILFN

There are several noise metrics which are used to quantify environmental noise levels. The most common metric is A-weighting (A-wt). The A-wt curve is shown in Figure 6. The A-wt metric is intended to approximate the loudness sensitive of the human ear for common environmental sounds in the range of 20 to 20,000 Hz. A-wt at 1 Hz is -149 dB. Hence a noise limit based on A-wt would not be appropriate to address ILFN, a major component of which is sound below 20 Hz.

A noise metric sometimes used when there is low frequency noise is the C-weighting (C-wt). While the C-wt metric does attempt to address low frequency noise better than A-wt, it would also not be appropriate for quantifying infrasound, since it still strongly de-emphasizes sound at frequencies below 20 Hz as shown in Figure 6. C-wt at 1 Hz is -52.5 dB.

One noise metric recently used to quantify ILFN is G-weighting (G-wt). The G-wt measure has been used in Europe. G-wt would certainly be a more representative measure of ILFN than

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[29] Alec Salt, and J.A. Kaltenbach, "Infrasound from Wind Turbines Could Affect Humans," Bulletin of Science, Technology and Society, 31(4), pp.296-302, September 12, 2011.

[30] Ibid., p. 300, "As discussed below, G-weighting (with values expressed in dBG) is one metric that is used to quantify environmental noise levels. While it is a more accurate measure of ILFN than most other metrics, G-weighting still de-emphasizes infrasound."

[31] Yasunao Matsumoto, et al, An investigation of the perception thresholds of band-limited low frequency noises; influence of bandwith, published in The Effects of Low-Frequency Noise and Vibration on People, Multi-Science Publishing Co. Ltd.

either the A- wt or the C- wt metrics, but as shown in Figure 6 it too de-emphasizes the very low frequency infrasound by -40 dB at 1 Hz.

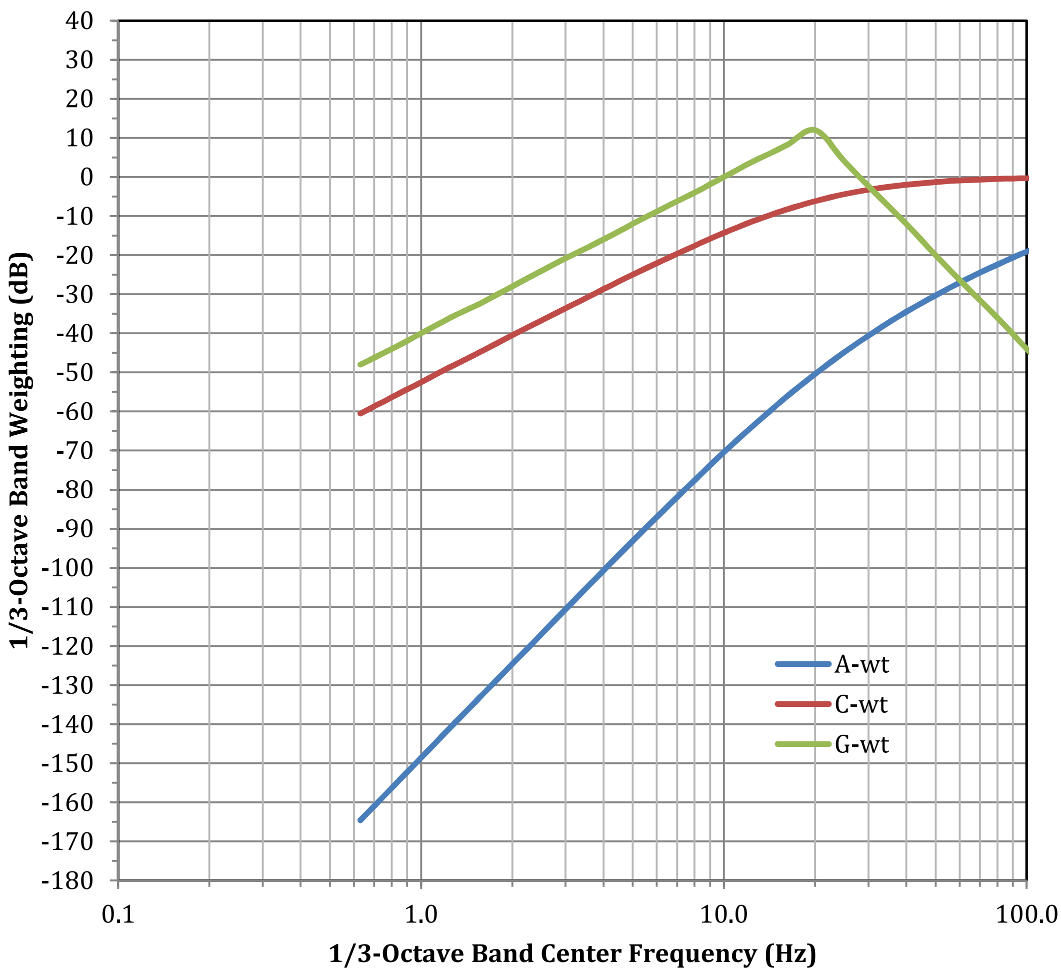


Figure 6 A, C and G Spectral Weighting Curves

CONCLUSION

The results of this study conclusively demonstrate that both the Kumeyaay and Ocotillo facilities' wind turbines generate ILFN at residential and other locations up to 15 miles away.

TERMINOLOGY

- Autospectrum: The autospectrum is the narrow band, energy average sound pressure level spectrum (in dB) measured for a specific time interval.
- Coherence: The spectral coherence is a statistic that can be used to examine the relation between two signals or data sets. It is commonly used to estimate the power transfer between input and output of a linear system. If the signals are ergodic, and the system function linear, it can be used to estimate the causality between the input and output.
- Cross-spectrum: In time series analysis, the cross-spectrum is used as part of a frequency domain analysis of the cross correlation or cross covariance between two time series.
- Cycles per second: A unit of frequency, same as hertz (Hz).
- Decibel (dB): A unit of level which denotes the ratio between two quantities that are proportional to power; the number of decibels is 10 times the logarithm (to the base 10) of this ratio. For sound, the reference sound pressure is 20 micro-Pascals.
- FFT (fast Fourier transform): An algorithm to compute the discrete Fourier transform and its inverse. A Fourier transform converts time to frequency and vice versa; an FFT rapidly computes such transformations.
- ILFN: Infrasound and low frequency noise.
- Infrasound: Sound at frequencies lower than 20 Hz.
- Low frequency noise: Noise at frequencies between 20 and 200 Hz.
- Noise level: The sound pressure energy measured in decibels.

APPENDIX A – MEASUREMENT LOCATIONS

Figure A - 1 Kumeyaay Measurement Locations

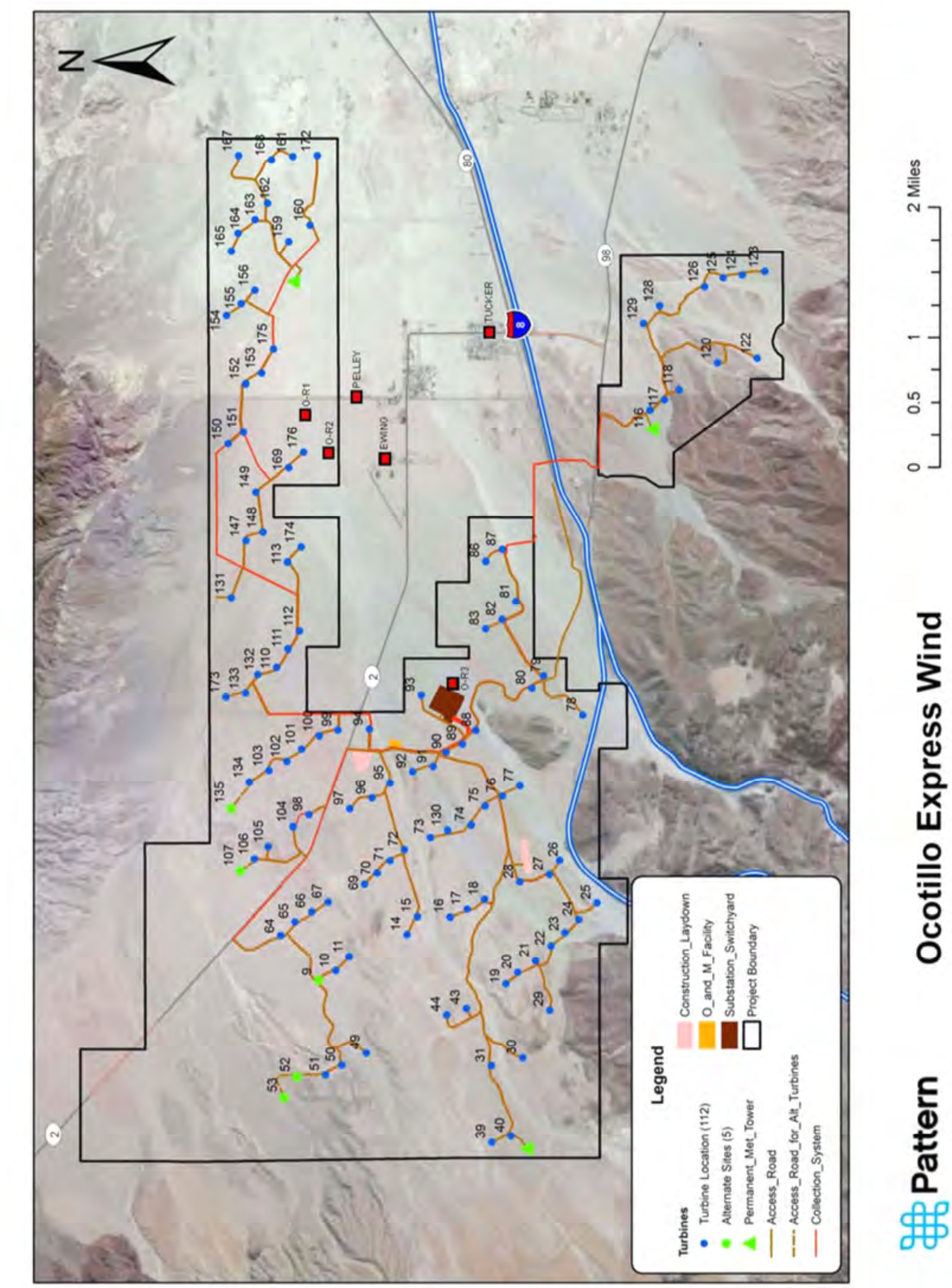


Figure A - 2 Ocotillo Measurement Locations

APPENDIX B – METEOROLOGICAL DATA

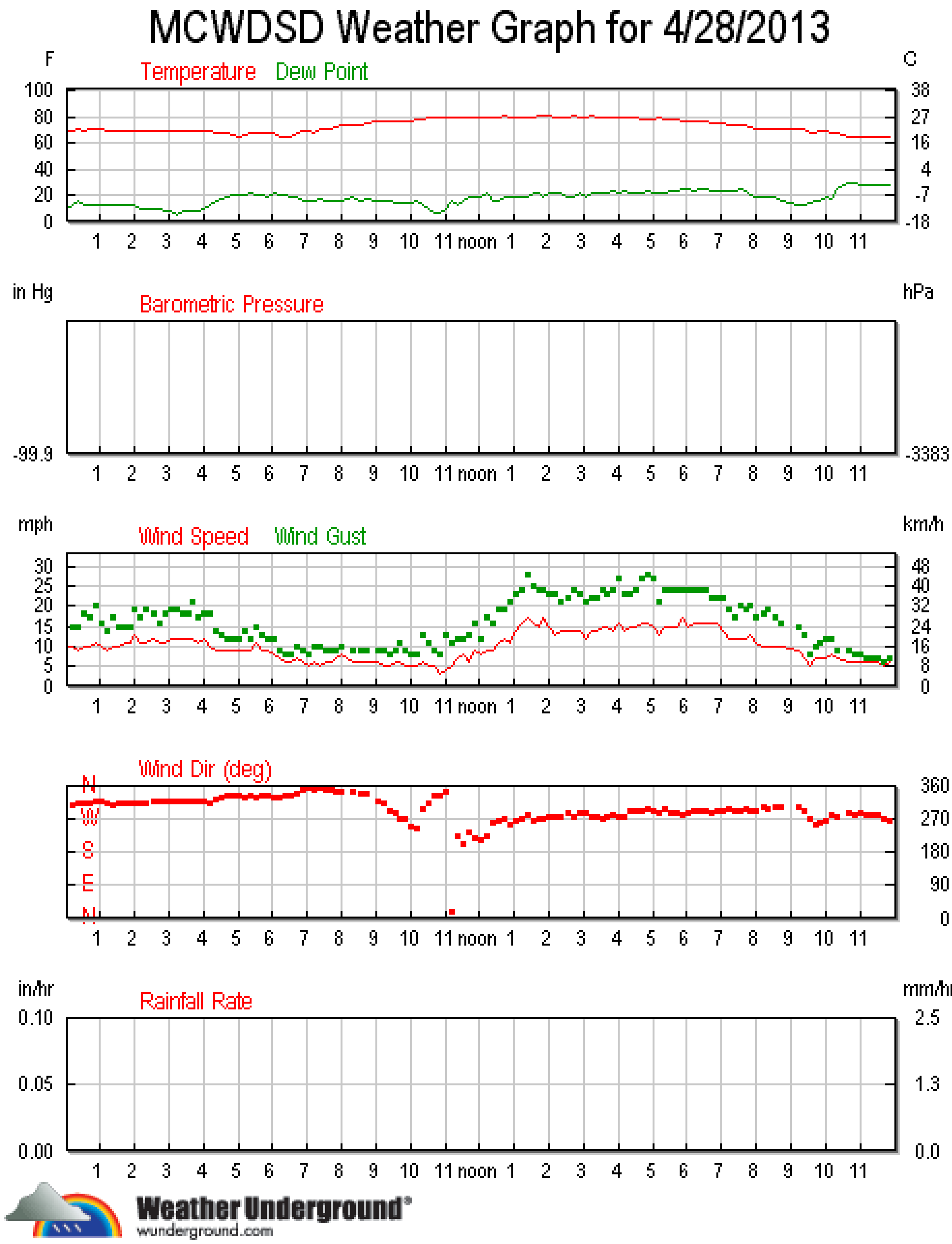


Figure B - 1 Weather Data for Kumeyaay 28 April 2013

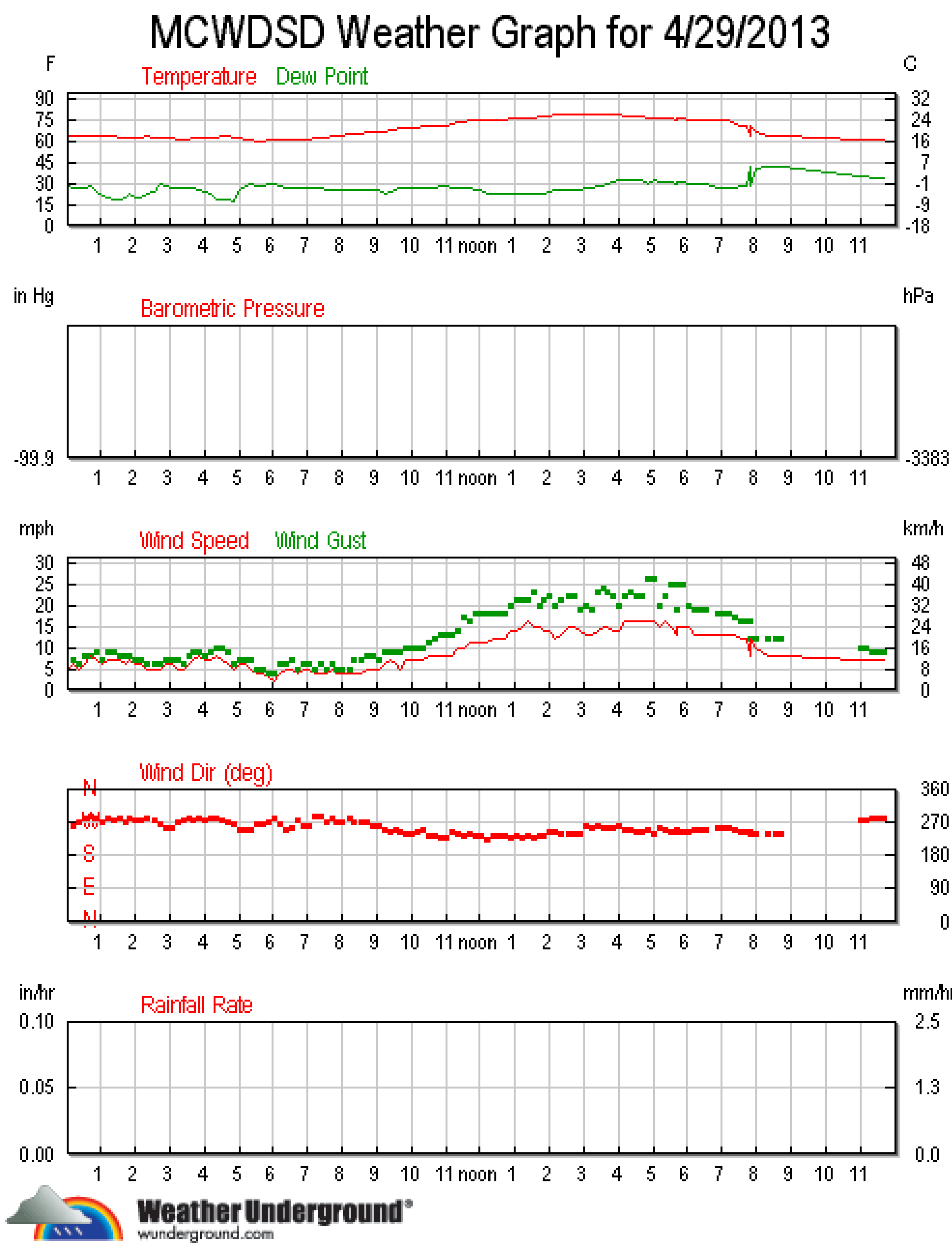


Figure B - 2 Weather Data for Kumeyaay April 29 2013

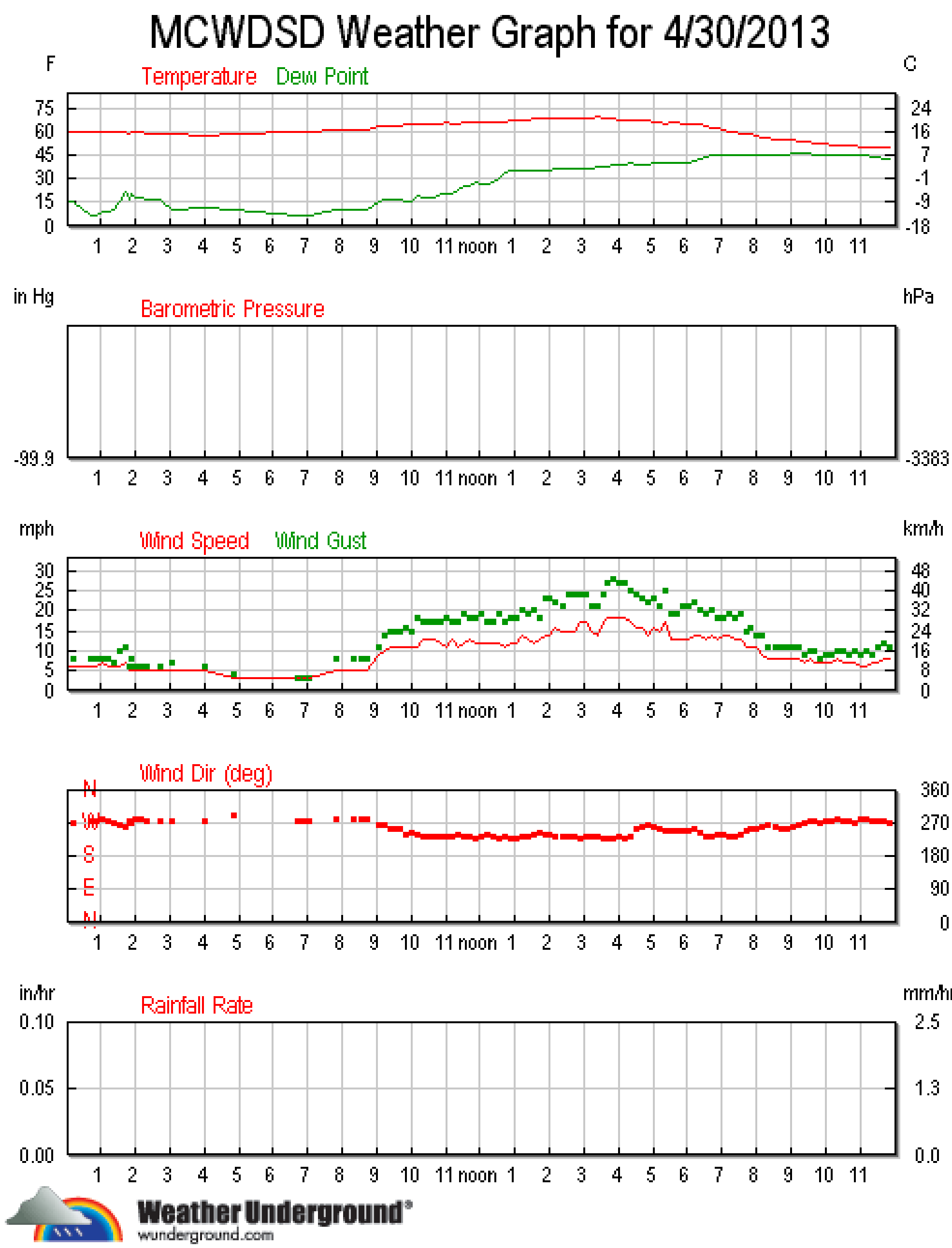


Figure B - 3 Weather Data for Kumeyaay 30 April 2013

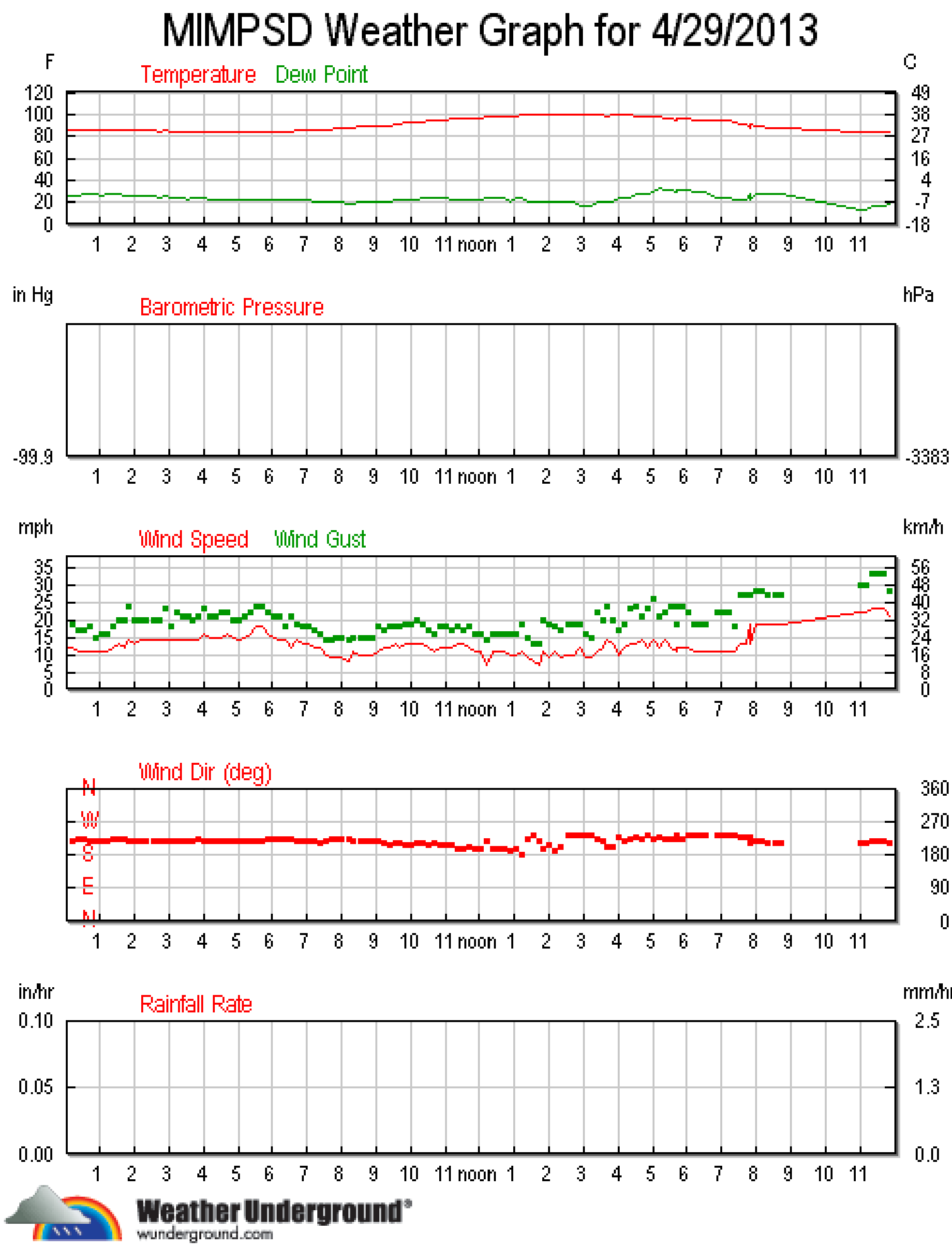


Figure B - 4 Weather Data for Ocotillo 29 April 2013

APPENDIX C – NOISE DATA

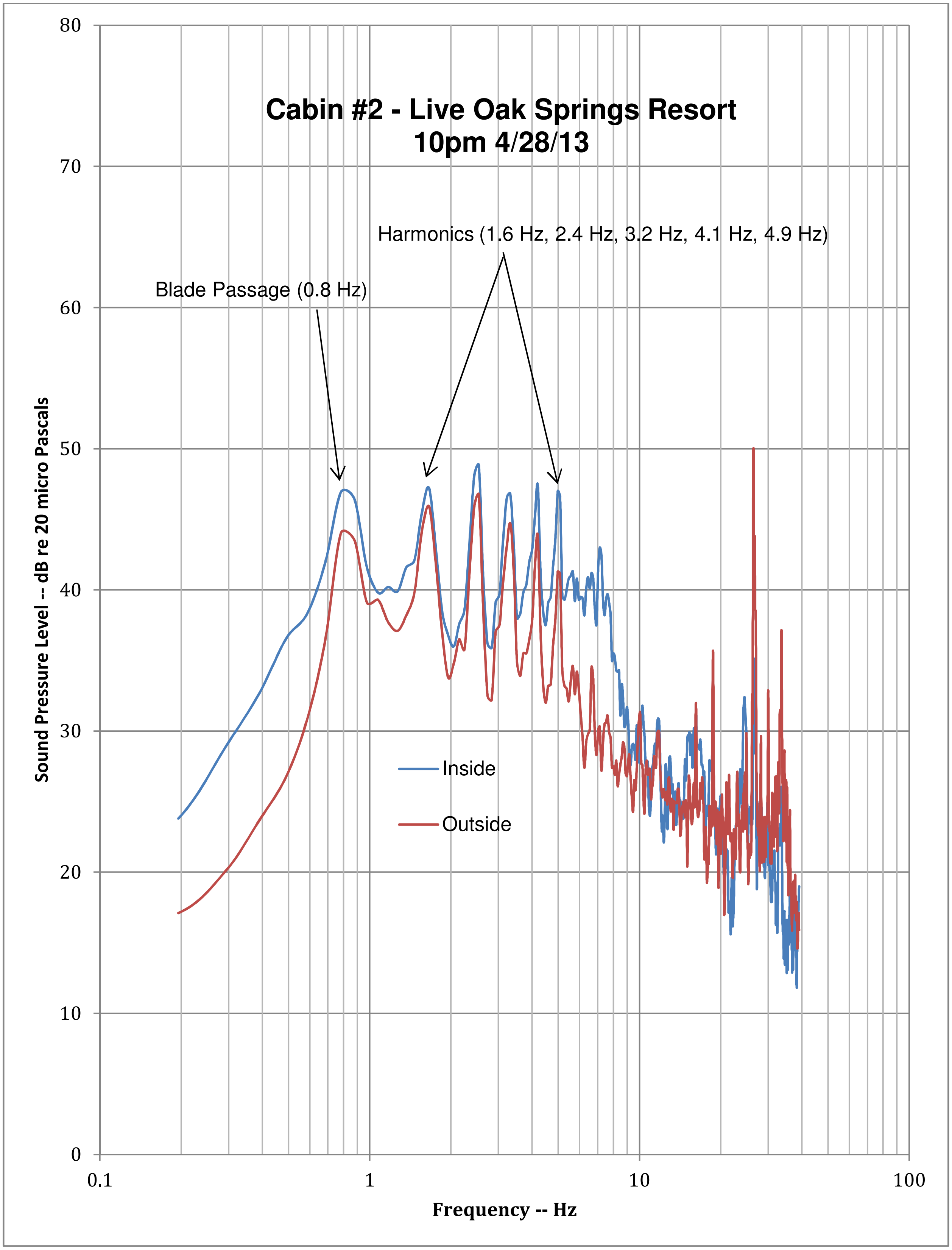
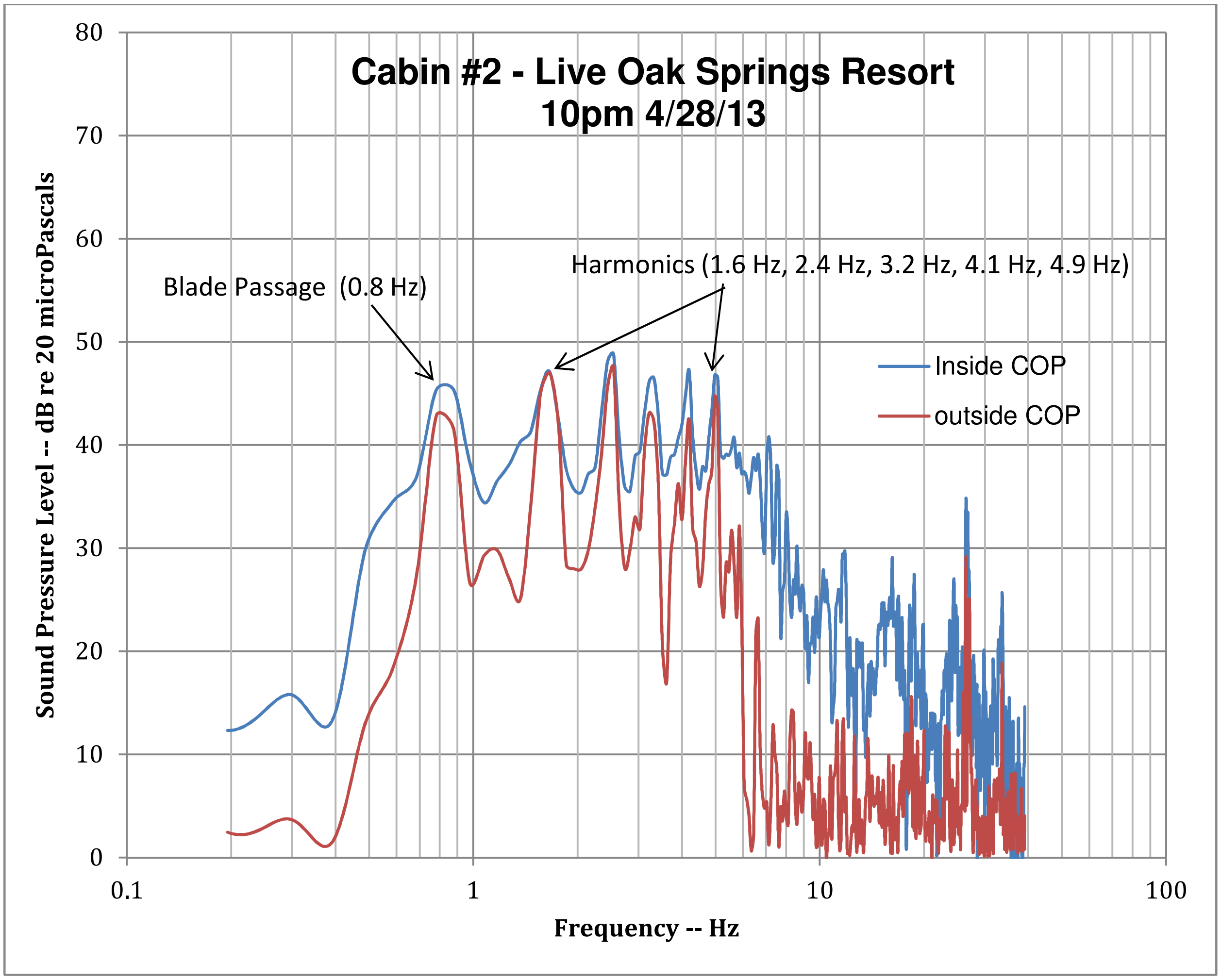


Figure C - 1 Live Oak Springs Resort – Cabin #2 – Autospectra



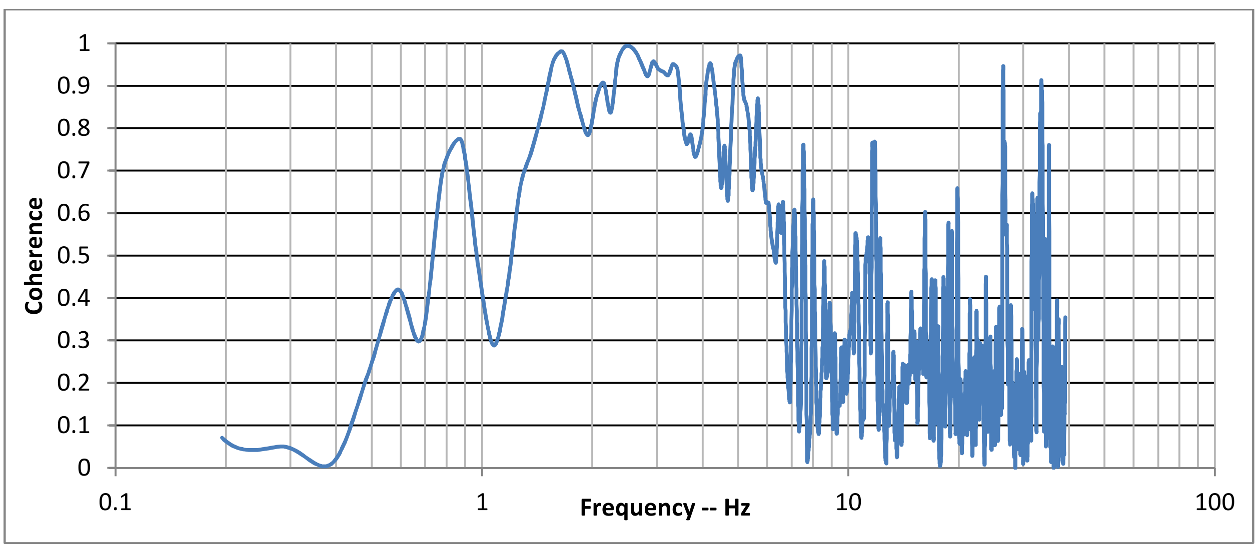


Figure C - 2 Live Oak Springs Resort – Cabin #2 – Coherent Output Power

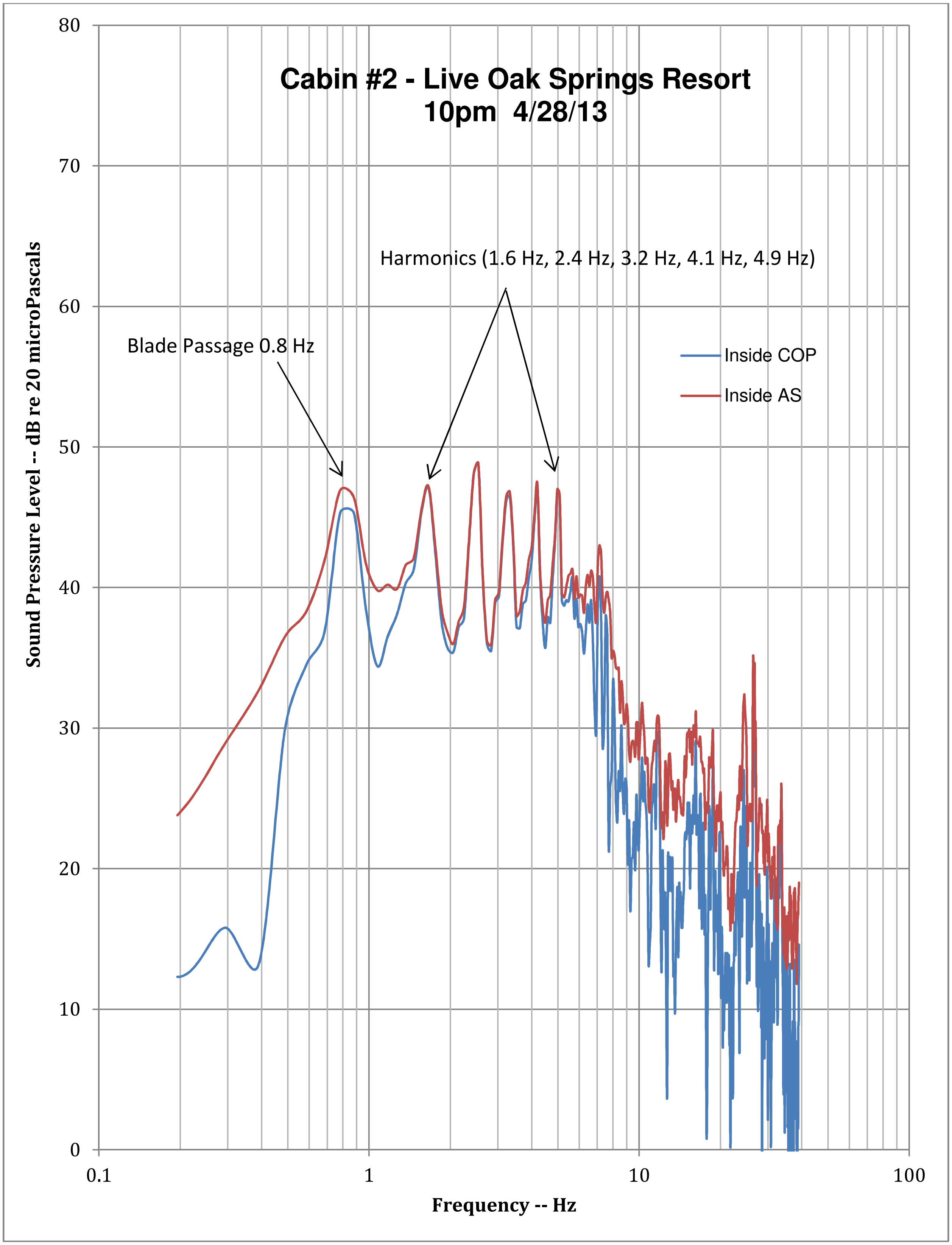


Figure C - 3 Live Oak Springs Resort – Cabin #2 – Comparison of Autospctrum and COP

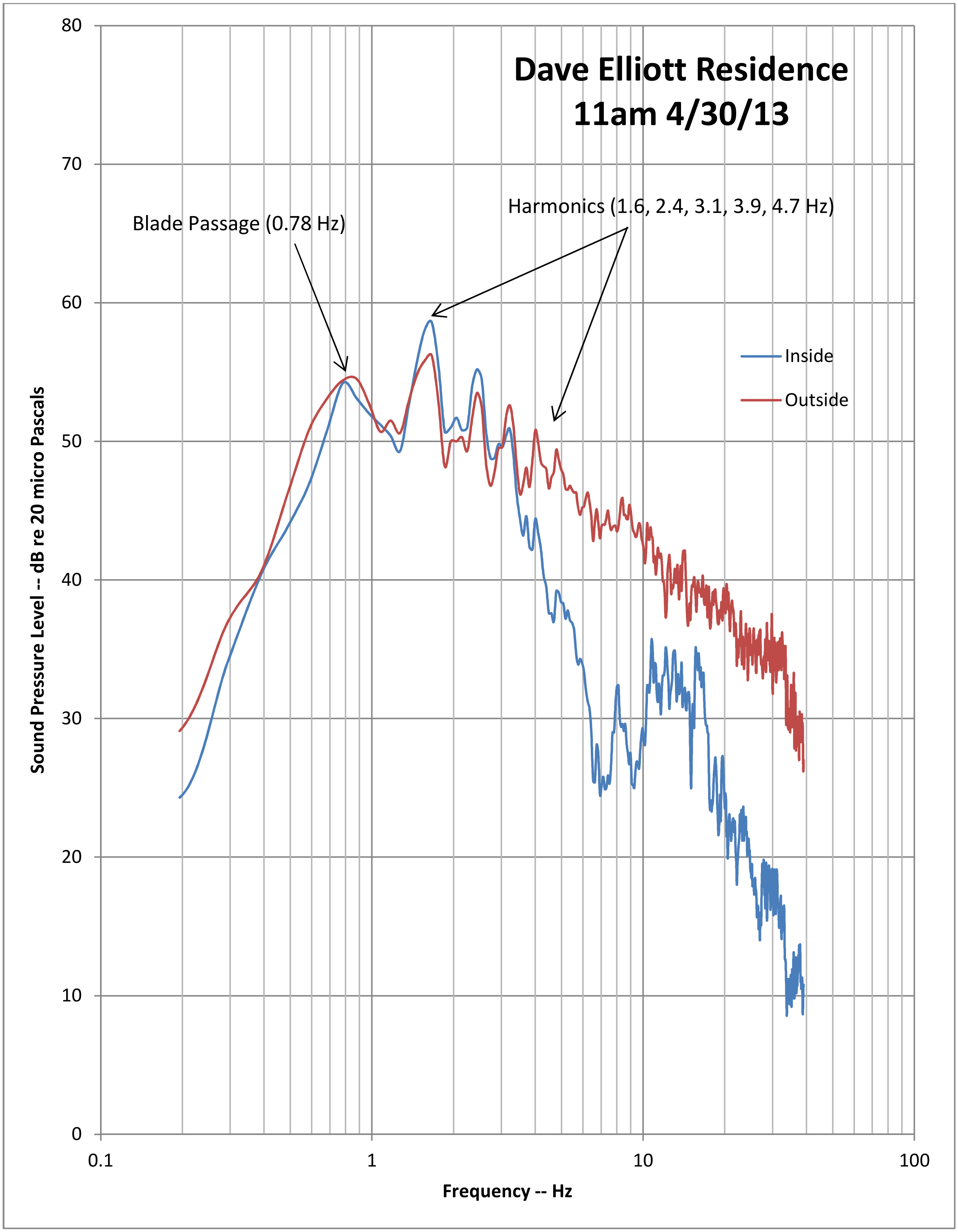


Figure C - 4 Dave Elliott Residence Autospectra

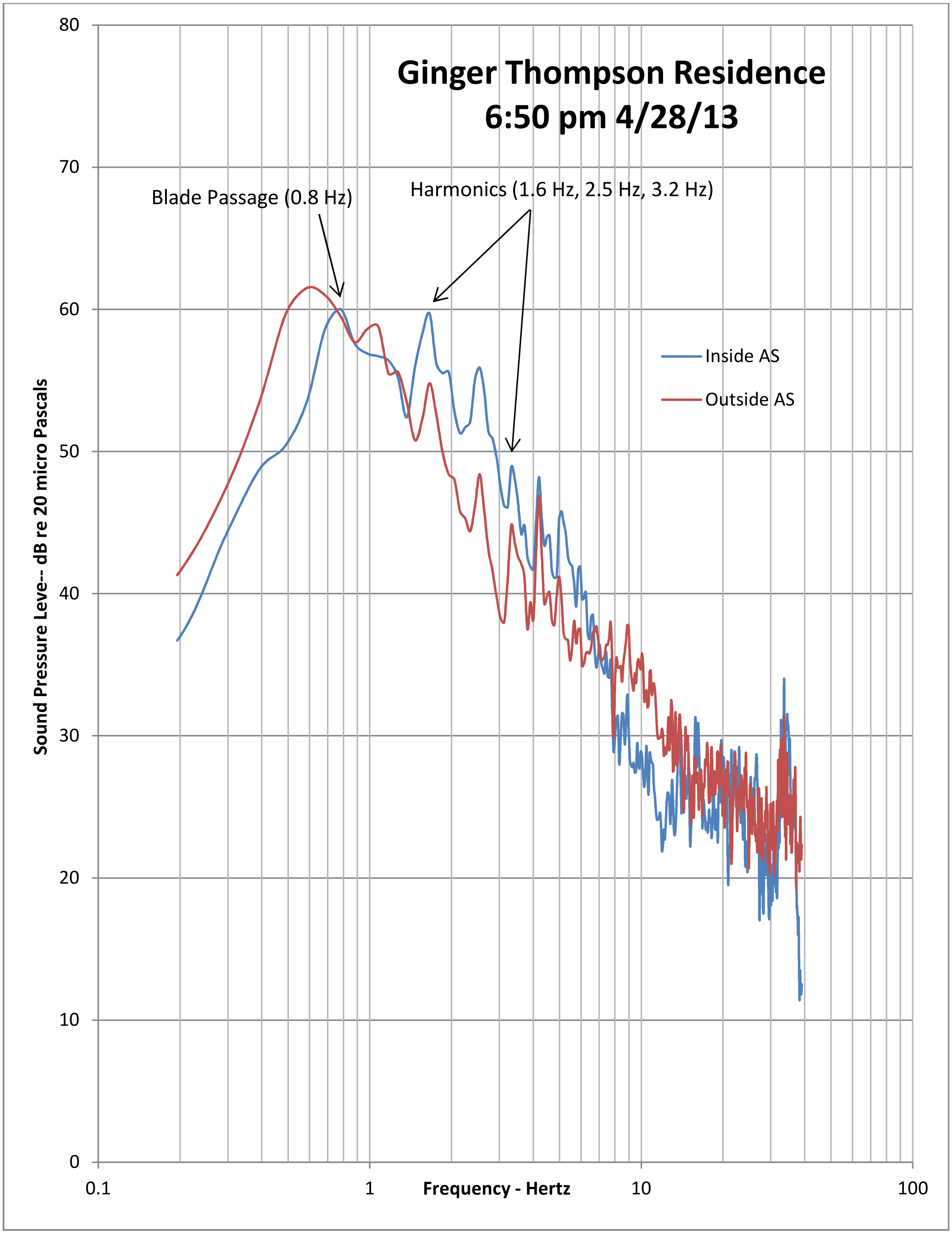


Figure C - 5 Ginger Thompson Residence Autospectra

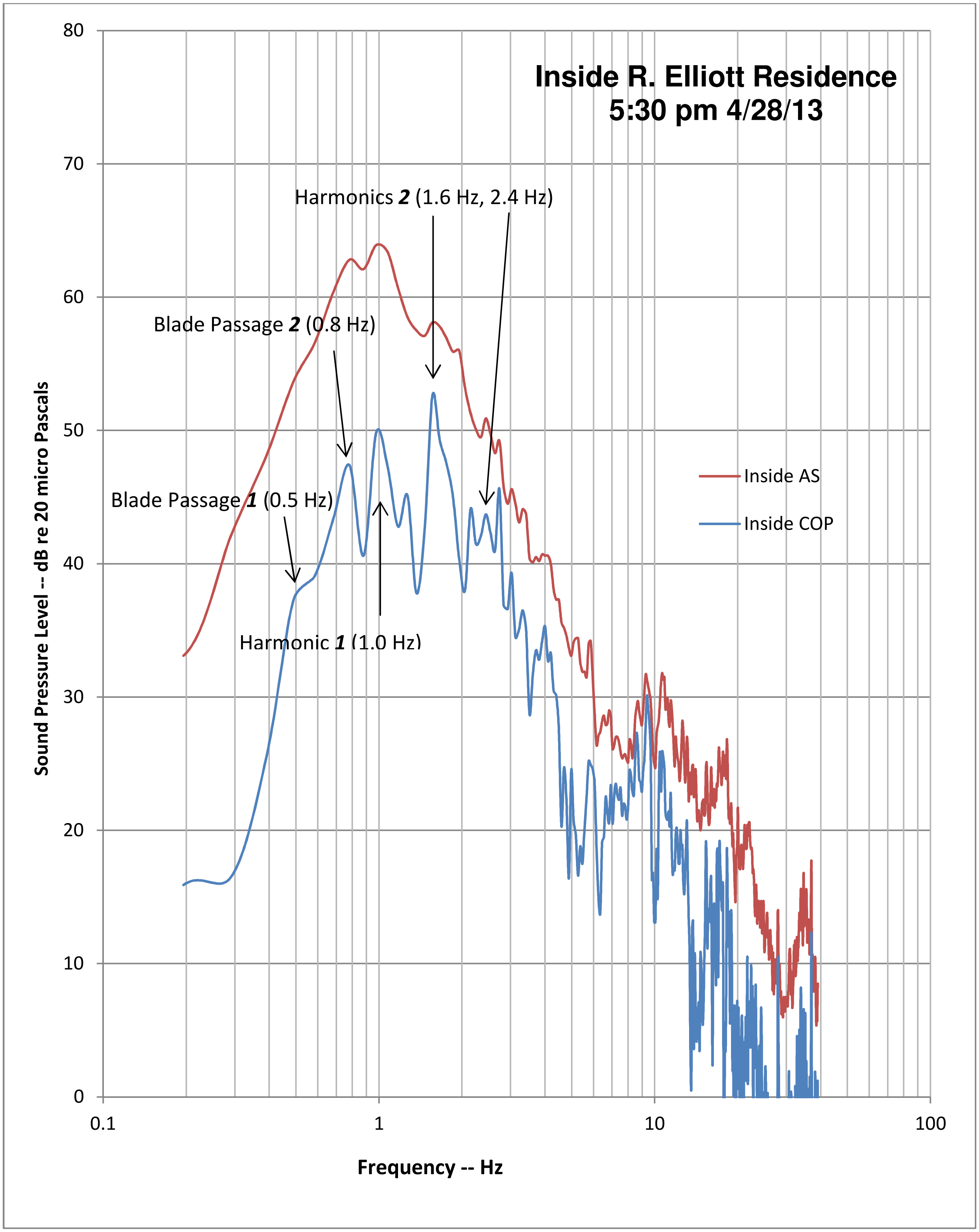


Figure C - 6 R. Elliott Residence Comparison of Autospectrum and Coherent Output Power

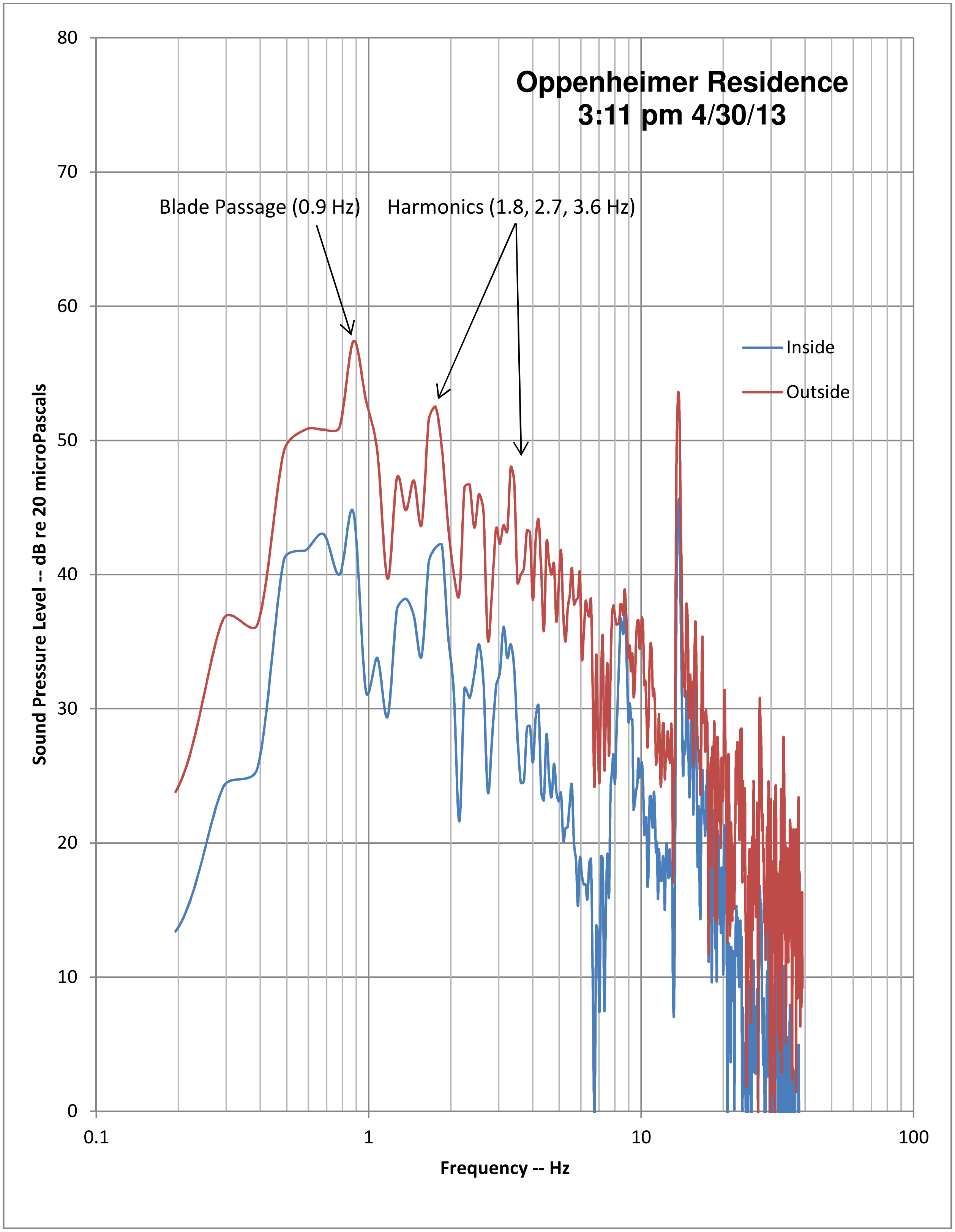


Figure C - 7 Ken Oppenheimer Residence during Day – Coherent Output Power

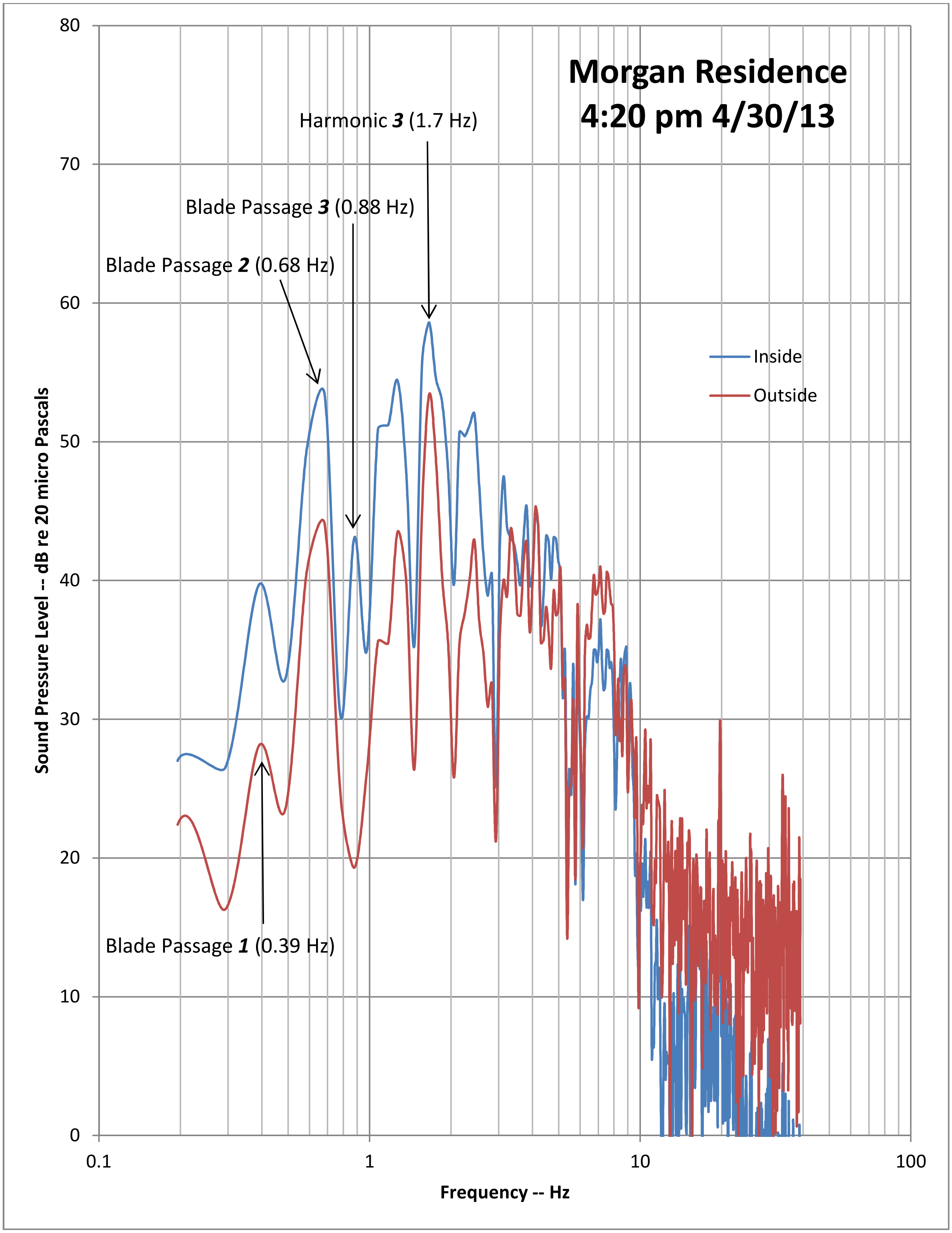


Figure C - 8 Marie Morgan Residence during Day – Coherent Output Power

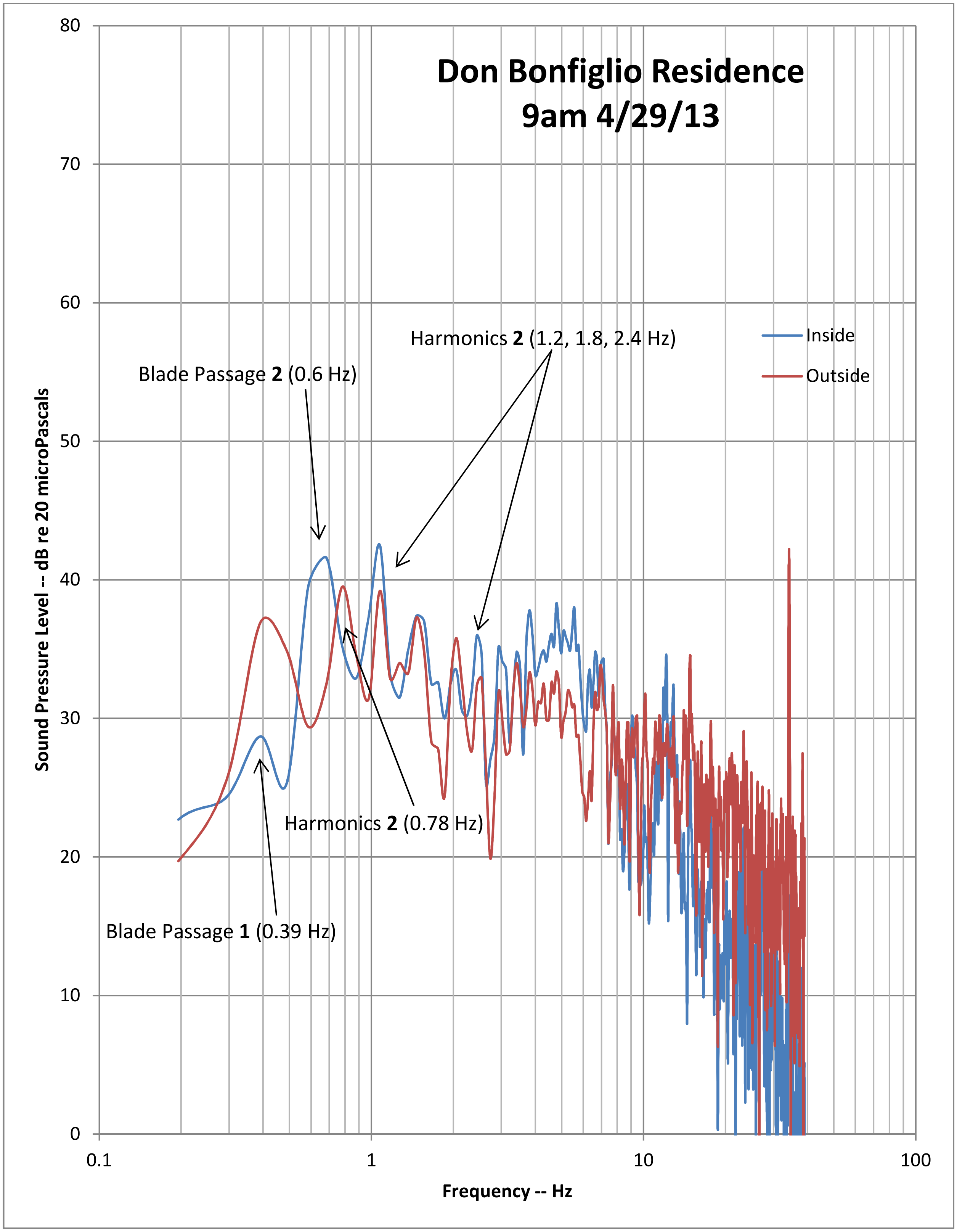


Figure C - 9 Don Bonfiglio Residence during Day – Coherent Output Power

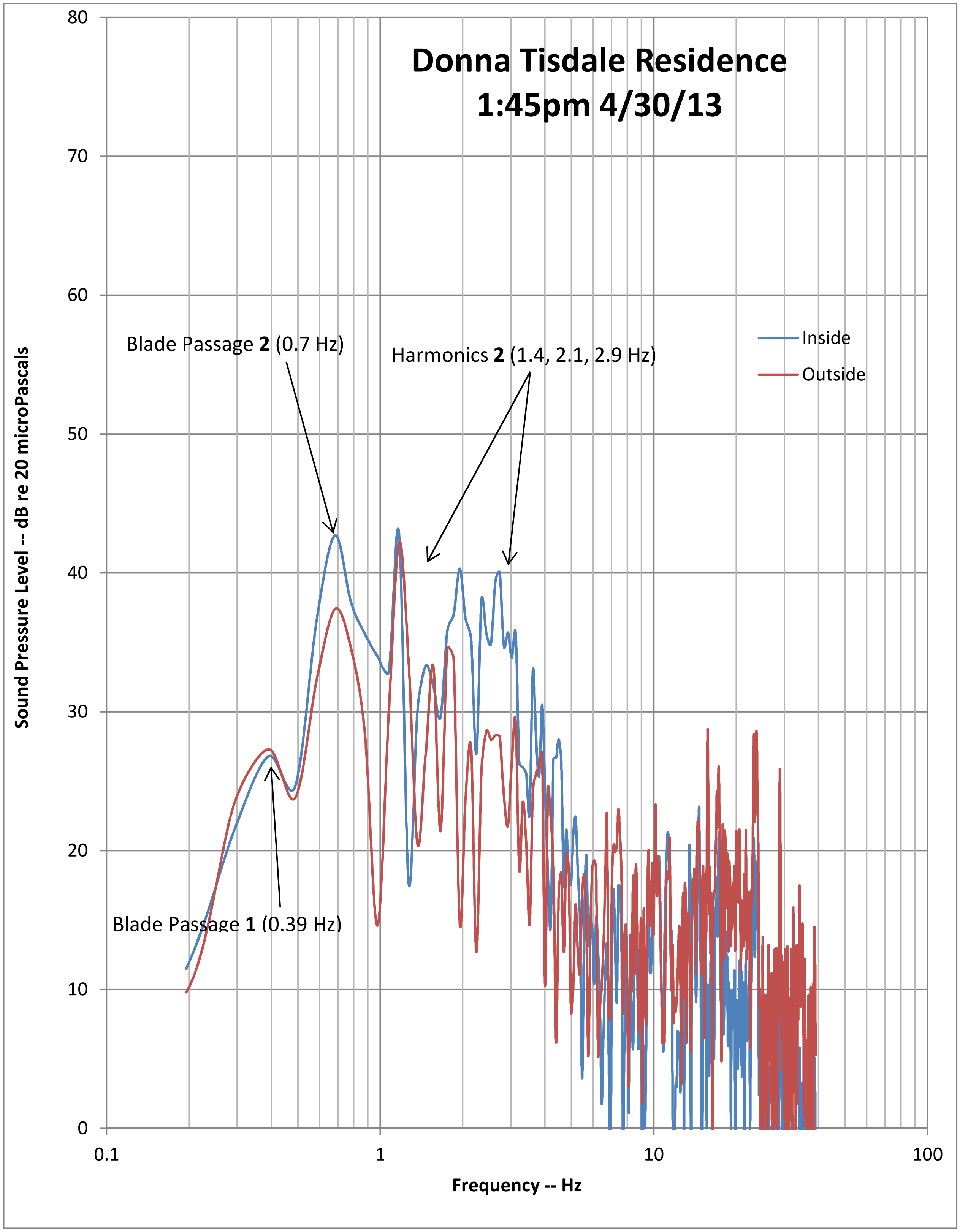


Figure C - 10 Donna Tisdale Residence during Day – Coherent Output Power

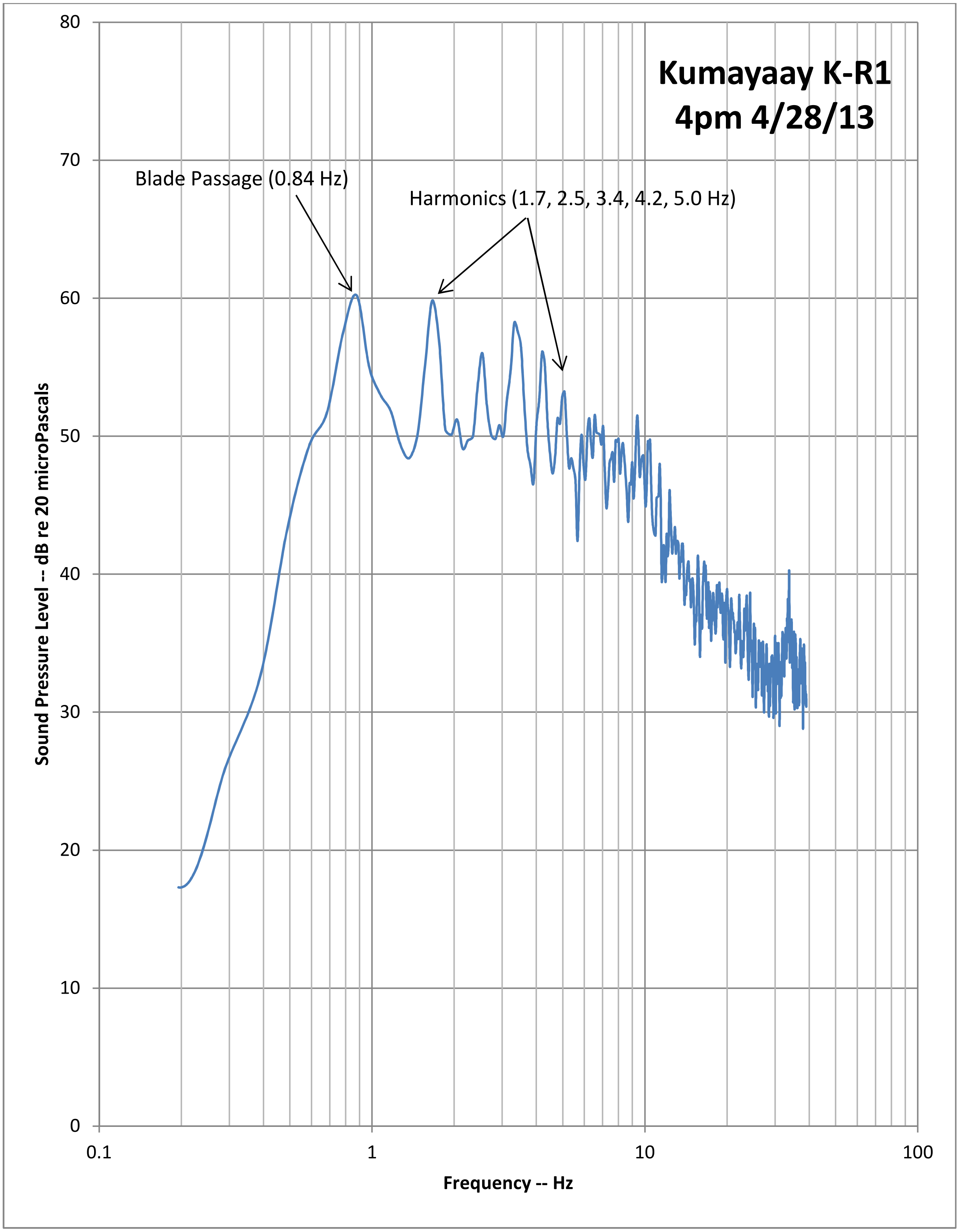


Figure C - 11 Kumeyaay Reference Location 1

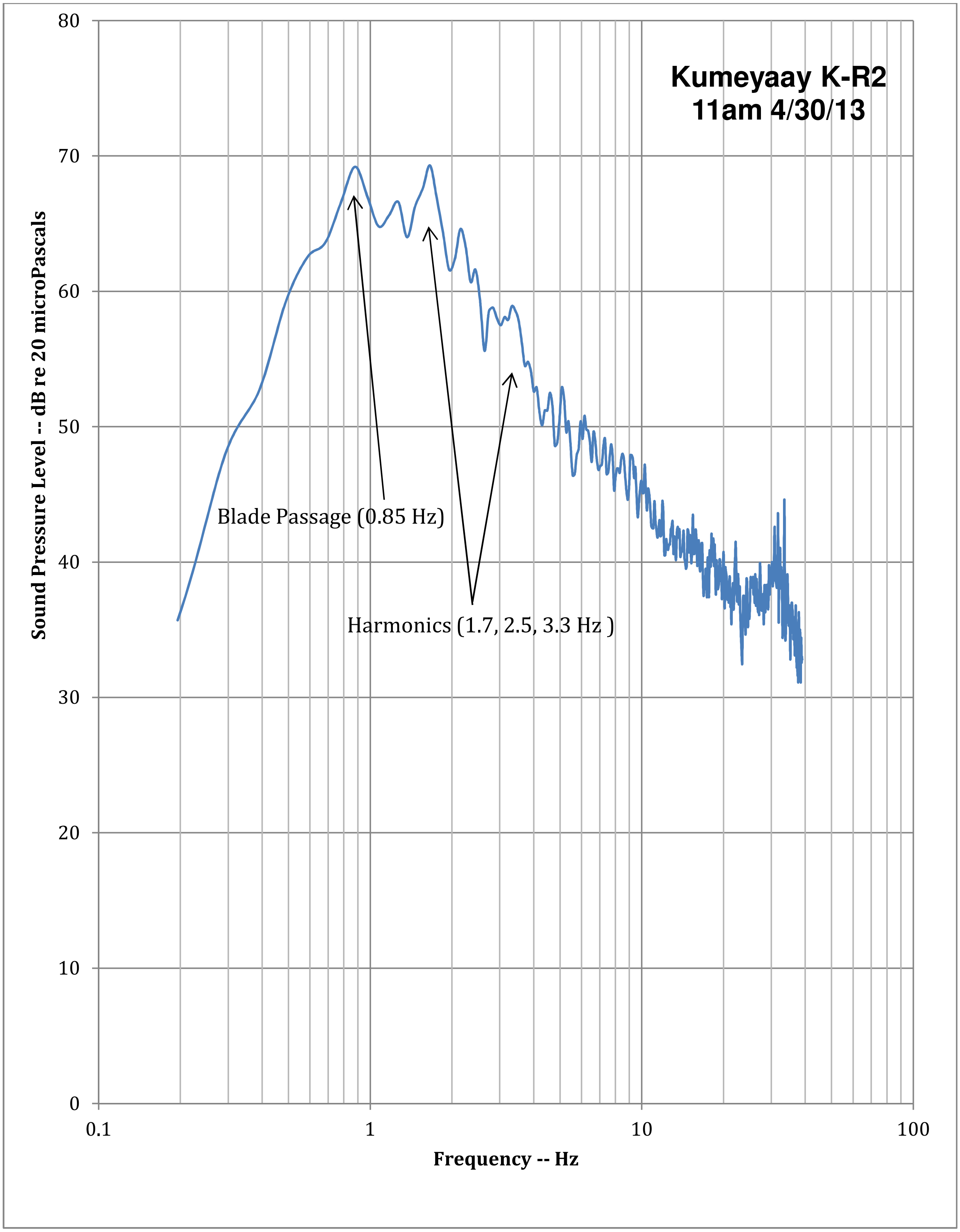


Figure C - 12 Kumeyaay Reference Location 2

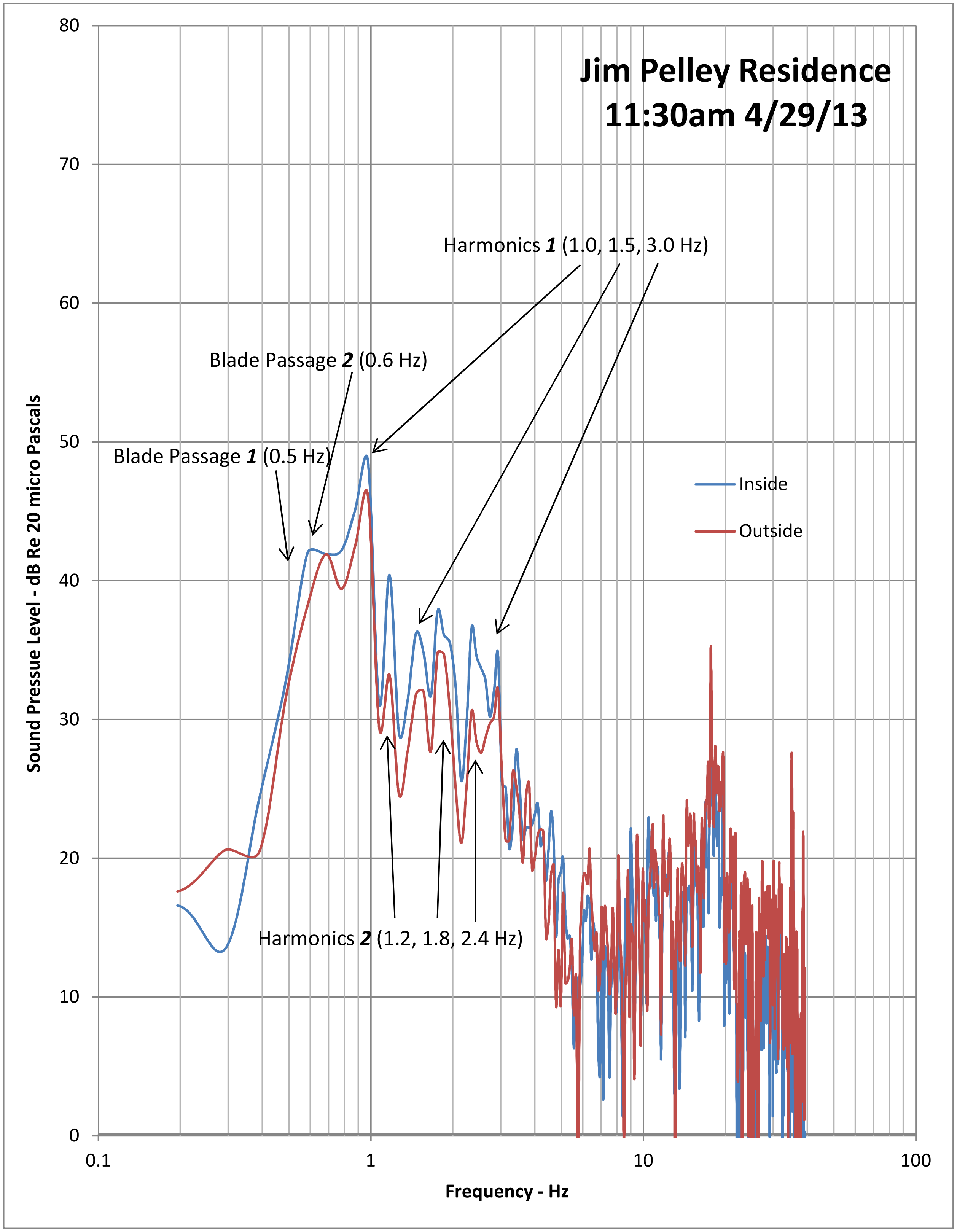


Figure C - 13 Jim Pelly Residence during Day – Coherent Output Power

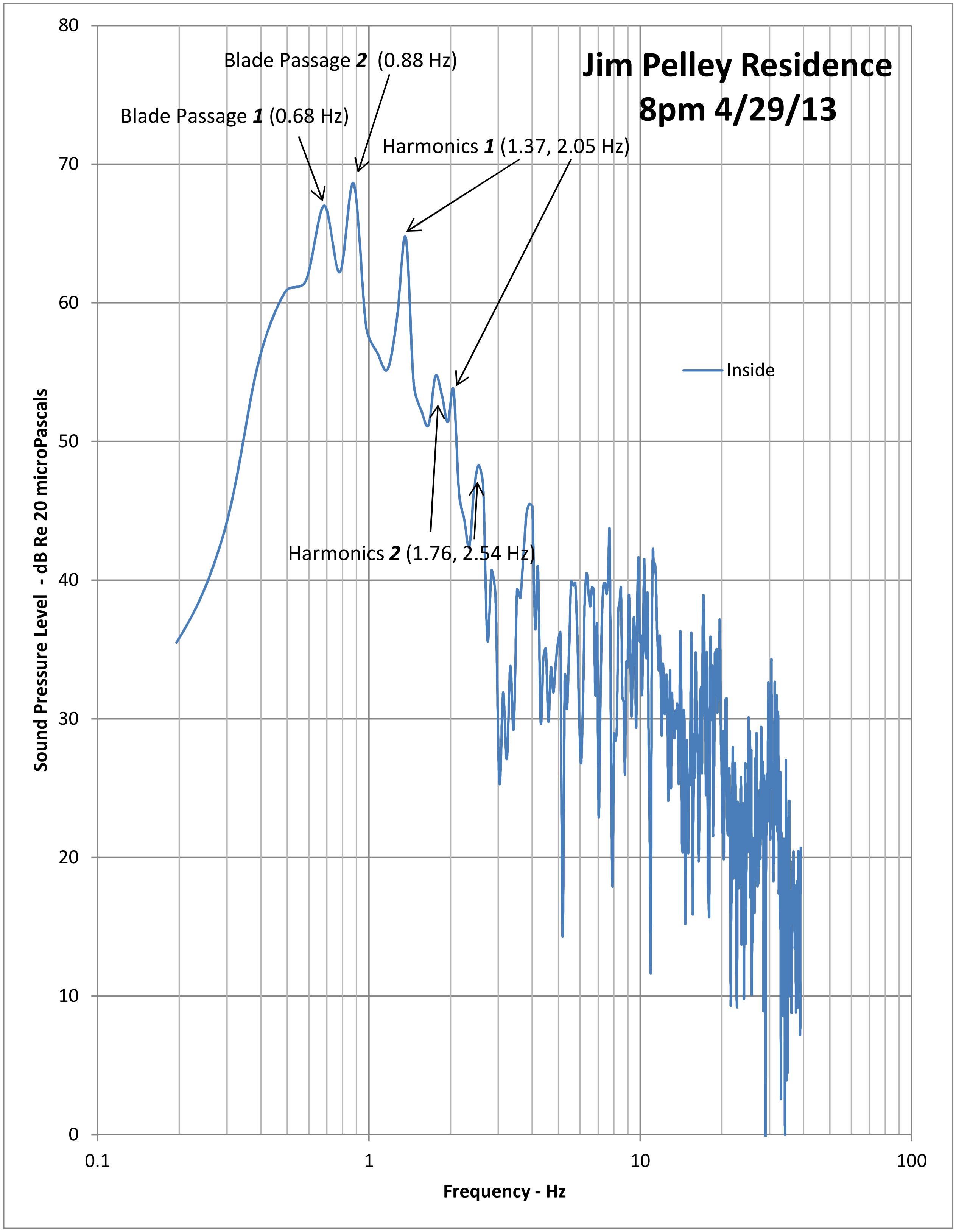


Figure C - 14 Jim Pelly Residence at Night – Coherent Output Power

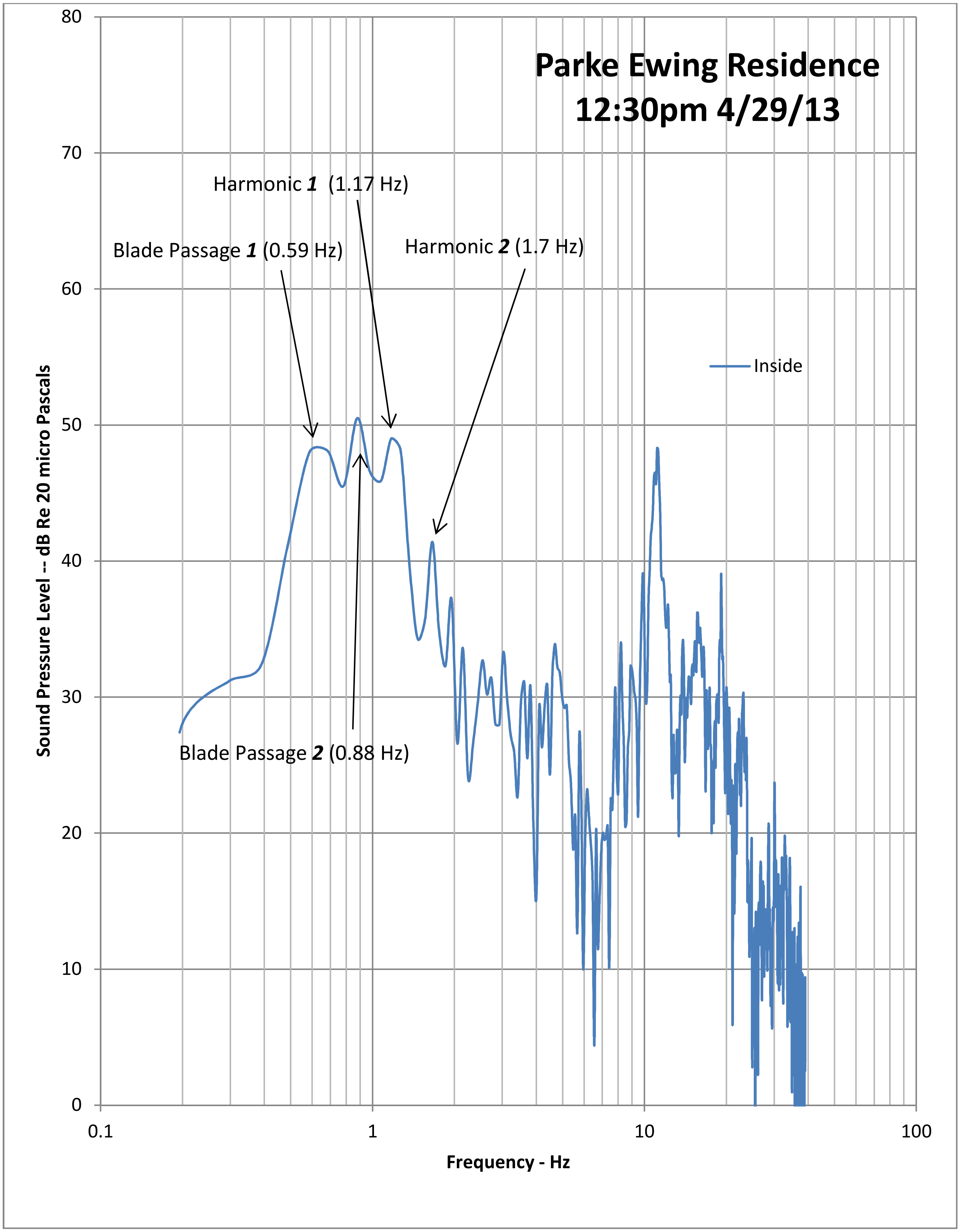


Figure C - 15 Parke Ewing Residence during Day – Coherent Output Power

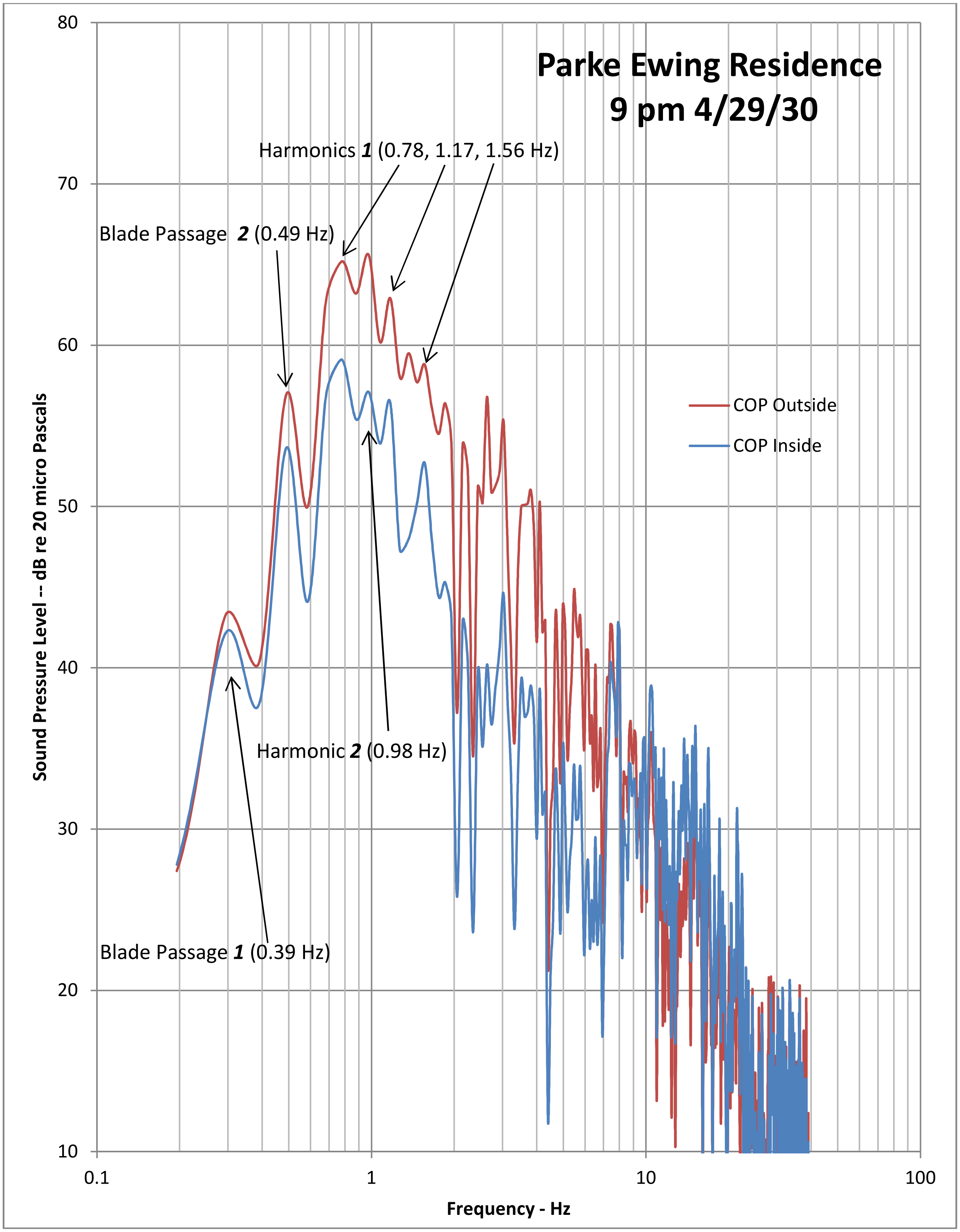


Figure C - 16 Parke Ewing Residence at Night – Coherent Output Power

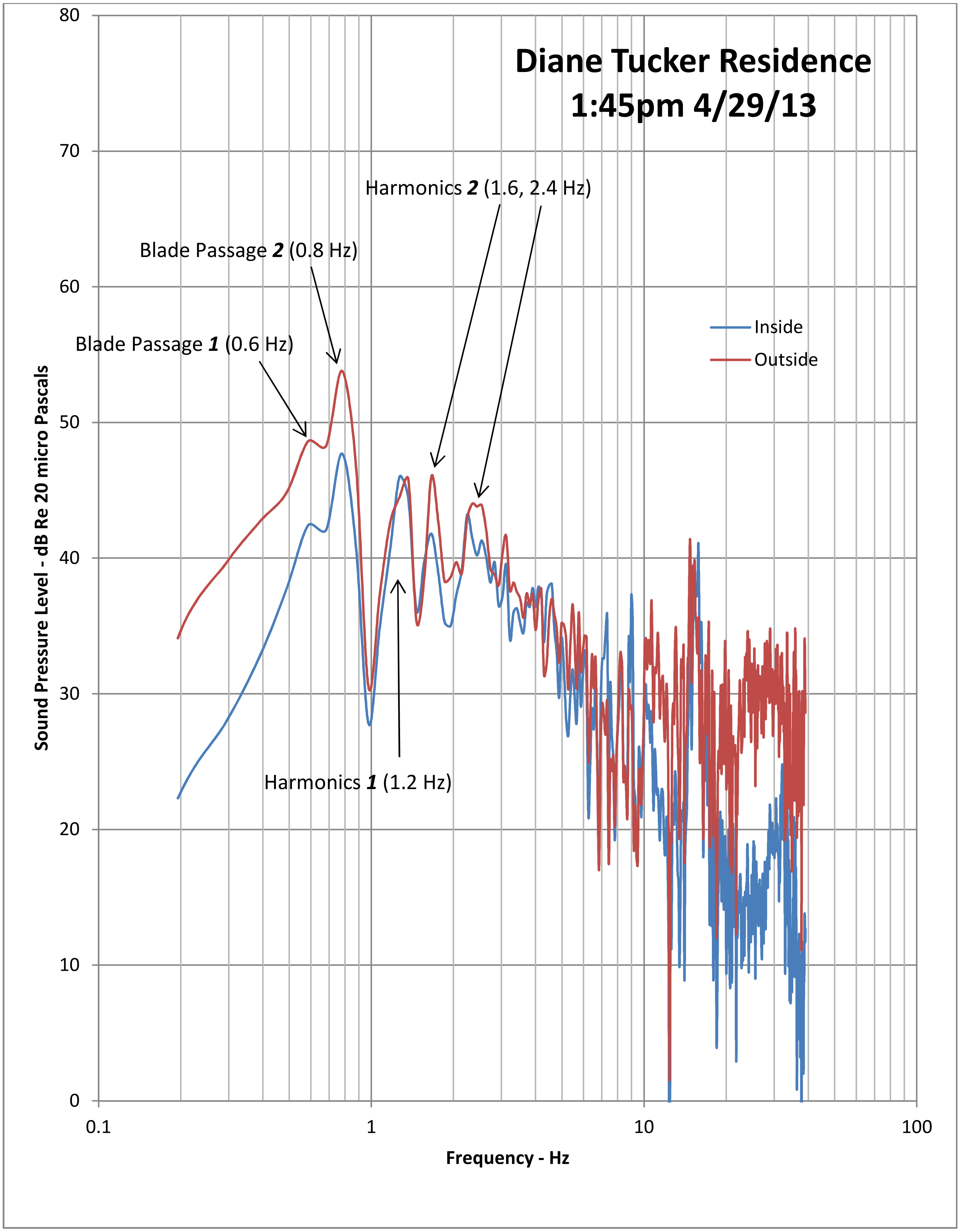


Figure C - 17 Diane Tucker Residence at Day – Coherent Output Power

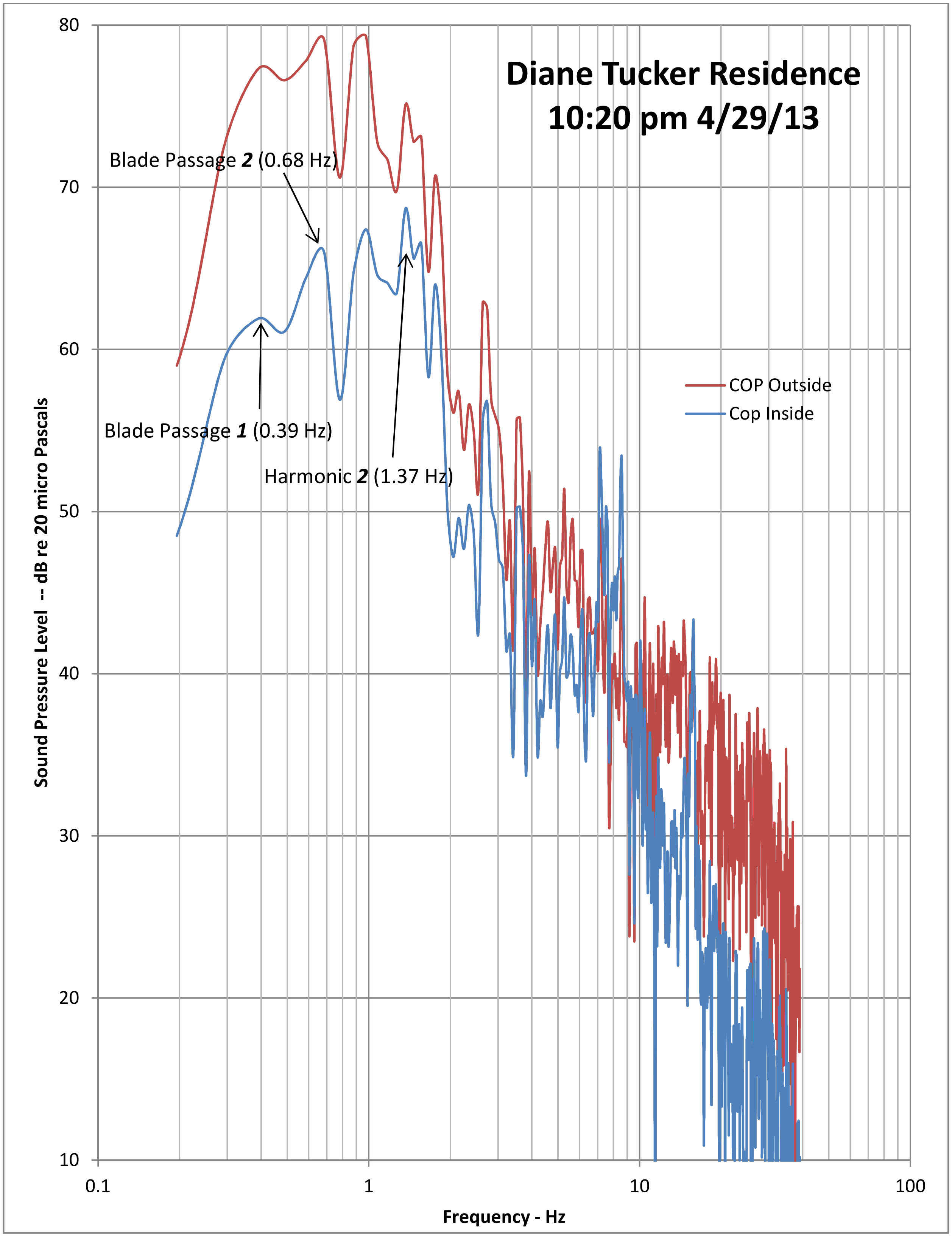


Figure C - 18 Diane Tucker Residence at Night – Coherent Output Power

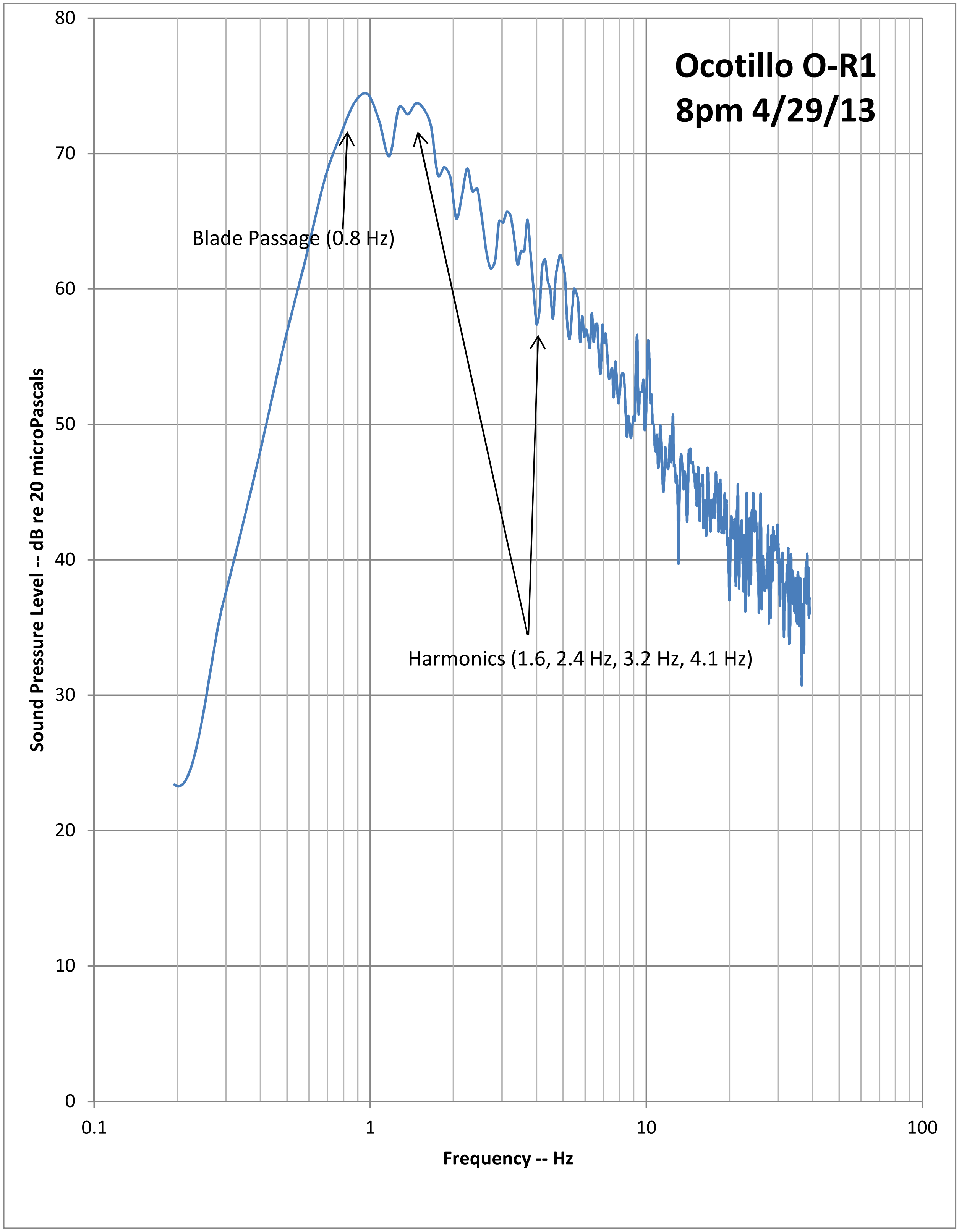


Figure C - 19 Ocotillo Reference Location 1 at Night

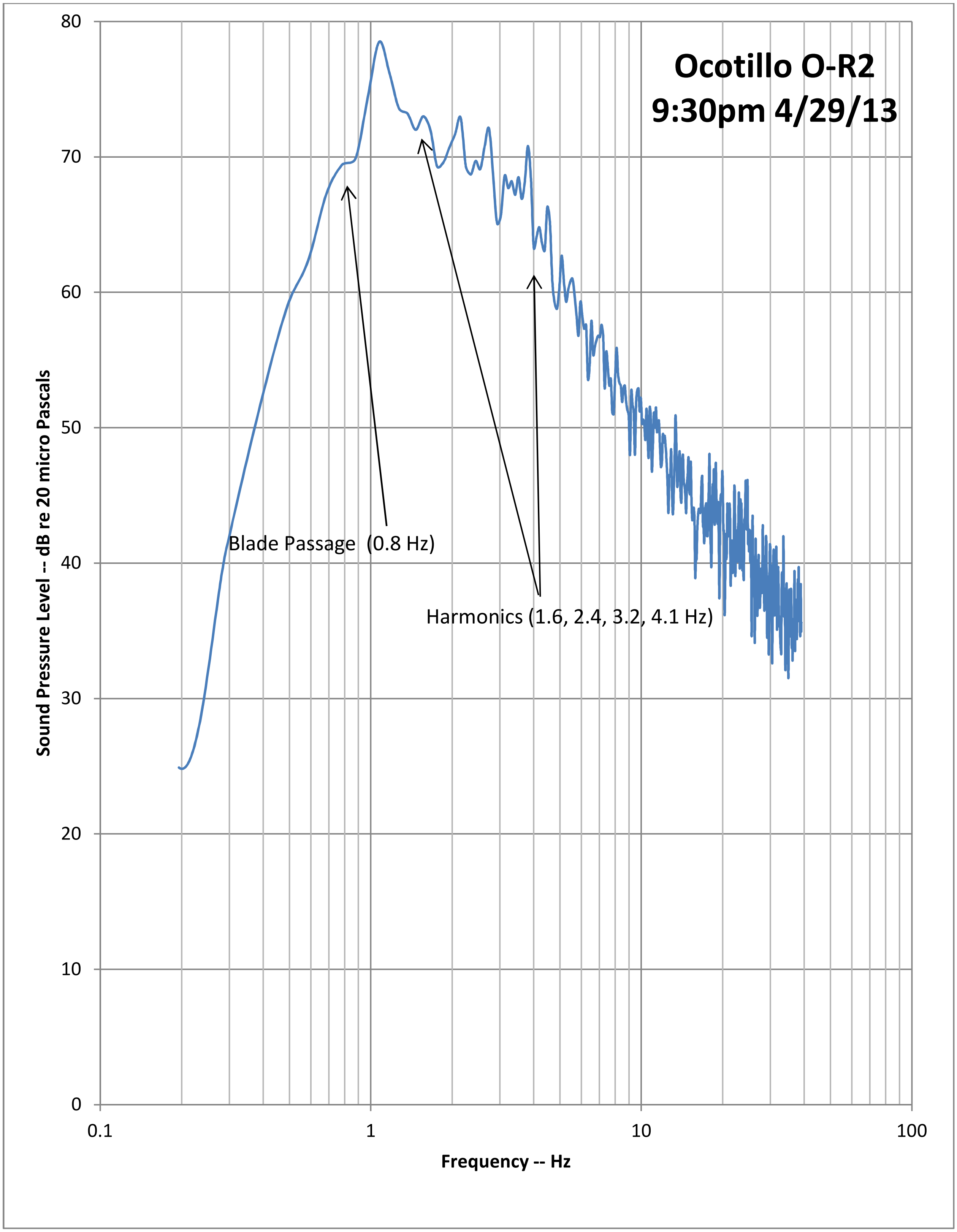


Figure C - 20 Ocotillo Reference Location 2 at Night

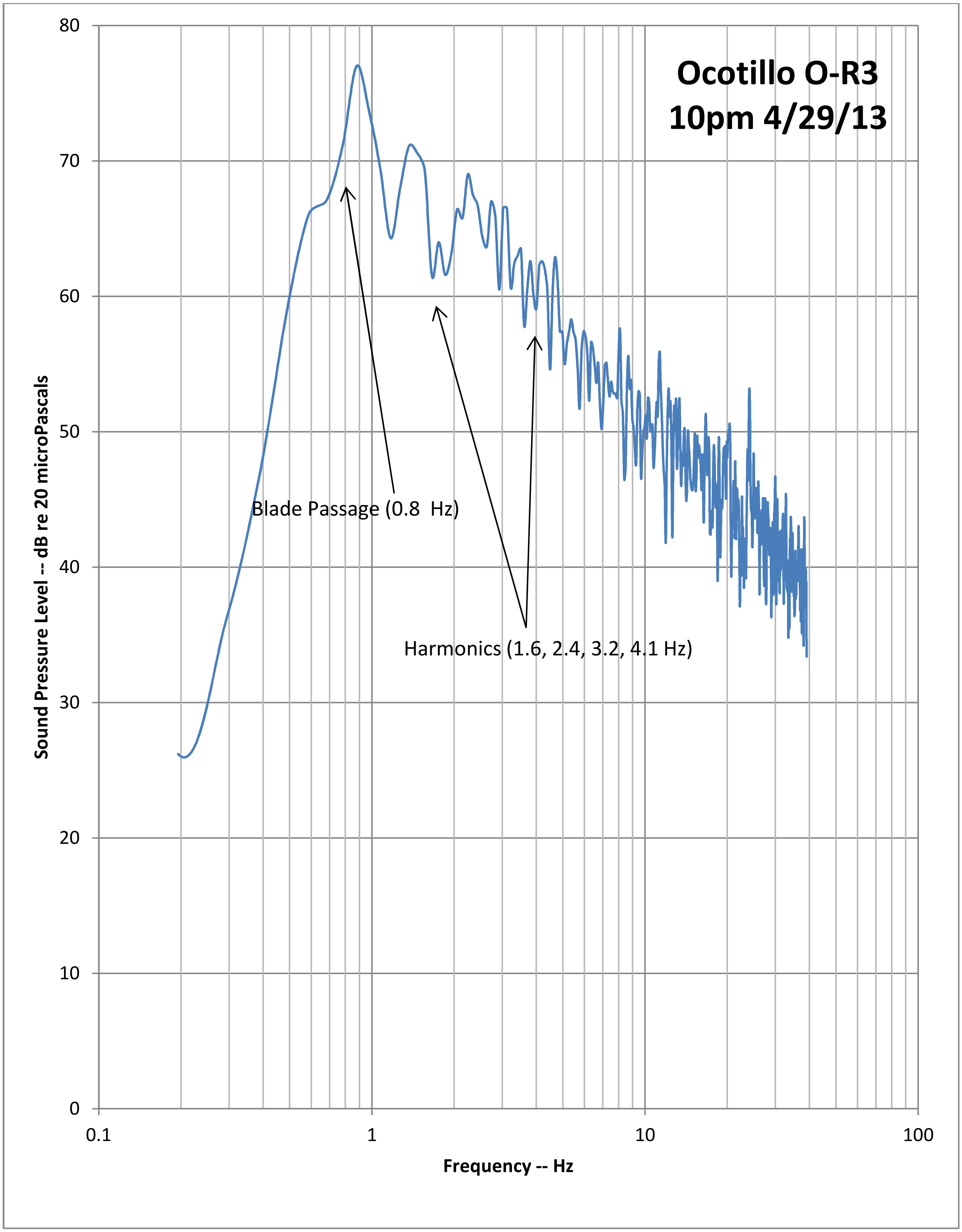
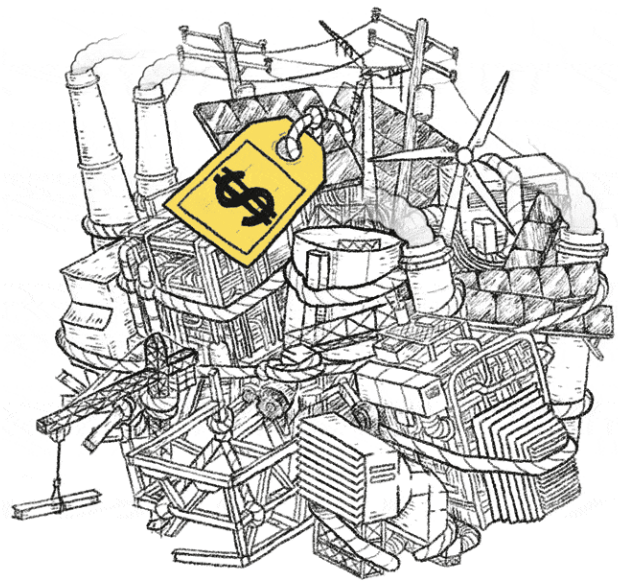


Figure C - 21 Ocotillo Reference Location 3 at Night

EXHIBIT
1

Los Angeles Times (HTTP://WWW.LATIMES.COM/)

Californians are paying billions for power they don't need



We're using less electricity. Some power plants have even shut down. So why do state officials keep approving new ones?

By IVAN PENN (HTTP://WWW.LATIMES.COM/LA-BIO-IVAN-PENN-STAFF.HTML) and RYAN MENEZES (HTTP://WWW.LATIMES.COM/LA-BIO-RYAN-MENEZES-STAFF.HTML) | Reporting from Yuba City, Calif.

FEB. 5, 2017

Read the story

View the graphic (/projects/la-fi-electricity-capacity-graphic/)

The bucolic orchards of Sutter County north of Sacramento had never seen anything like it: a visiting governor and a media swarm — all to christen the first major natural gas power plant in California in more than a decade.

At its 2001 launch, the Sutter Energy Center was hailed as the nation's cleanest power plant. It generated electricity while using less water and natural gas than older designs.

A year ago, however, the $300-million plant closed indefinitely, just 15 years into an expected 30- to 40-year lifespan. The power it produces is no longer needed — in large part because state regulators approved the construction of a plant just 40 miles away in Colusa that opened in 2010.

"We are building more power plants in California than ever before. Our goal is to make California energy self-sufficient." - Gov. Gray Davis at the opening of Sutter Energy Center in 2001. (Carolyn Cole / Los Angeles Times)

Sutter Energy Center has been offline since 2016, after just 15 years of an expected 30- to 40-year lifespan. (David Butow / For The Times)

Two other large and efficient power plants in California also are facing closure decades ahead of schedule. Like Sutter, there is little need for their electricity.

California has a big — and growing — glut of power, an investigation by the Los Angeles Times has found. The state's power plants are on track to be able to produce at least 21% more electricity than it needs by 2020, based on official estimates. And that doesn't even count the soaring production of electricity by rooftop solar panels that has added to the surplus.

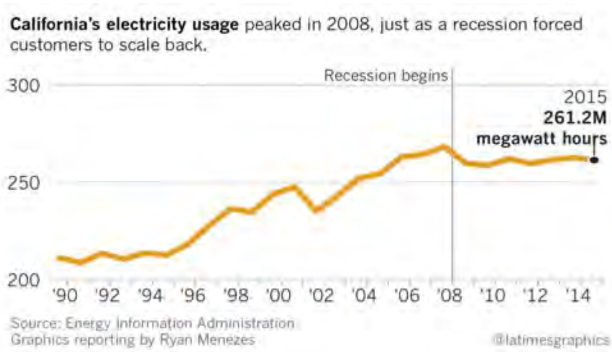
To cover the expense of new plants whose power isn't needed — Colusa, for example, has operated far below capacity since opening — Californians are paying a higher premium to switch on lights or turn on electric stoves. In recent years, the gap between what Californians pay versus the rest of the country has nearly doubled to about 50%.

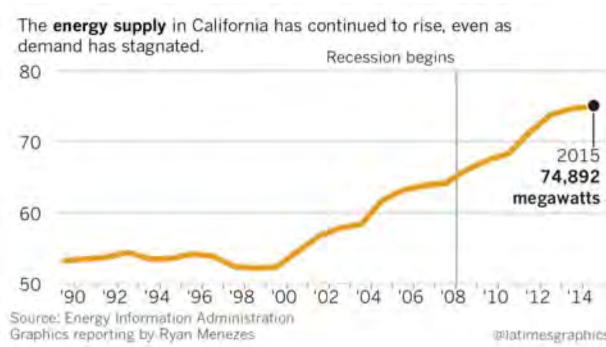
This translates into a staggering bill. Although California uses 2.6% less electricity annually from the power grid now than in 2008, residential and business customers together pay $6.8 billion more for power than they did then. The added cost to customers will total many billions of dollars over the next two decades, because regulators have approved higher rates for years to come so utilities can recoup the expense of building and maintaining the new plants, transmission lines and related equipment, even if their power isn't needed.

How this came about is a tale of what critics call misguided and inept decision-making by state utility regulators, who have ignored repeated warnings going back a decade about a looming power glut.

"In California, we're blinding ourselves to the facts," said Loretta Lynch, a former president of the California Public Utilities Commission, who along with consumer advocacy groups has fought to stop building plants. "We're awash in power at a premium price."

California regulators have for years allowed power companies to go on a building spree, vastly expanding the potential electricity supply in the state. Indeed, even as electricity demand has fallen since 2008, California's new plants have boosted its capacity enough to power all of the homes in a city the size of Los Angeles — six times over. Additional plants approved by regulators will begin producing more electricity in the next few years.





The missteps of regulators have been compounded by the self-interest of California utilities, Lynch and other critics contend. Utilities are typically guaranteed a rate of return of about 10.5% for the cost of each new plant regardless of need. This creates a major incentive to keep construction going: Utilities can make more money building new plants than by buying and reselling readily available electricity from existing plants run by competitors.

Regulators acknowledge the state has too much power but say they are being prudent. The investment, they maintain, is needed in case of an emergency — like a power plant going down unexpectedly, a heat wave blanketing the region or a wildfire taking down part of the transmission network.

"We overbuilt the system because that was the way we provided that degree of reliability," explained Michael Picker, president of the California Public Utilities Commission. "Redundancy is important to reliability."

Some of the excess capacity, he noted, is in preparation for the retirement of older, inefficient power plants over the next several years. The state is building many new plants to try to meet California environmental standards requiring 50% clean energy by 2030, he said.

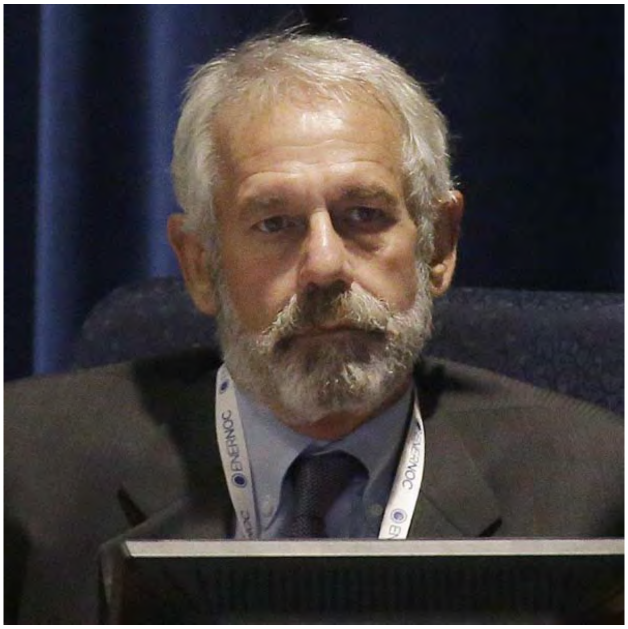
In addition, he said, some municipalities — such as the Los Angeles Department of Water and Power — want to maintain their own separate systems, which leads to inefficiencies and redundancies. "These are all issues that people are willing to pay for," Picker said.

Critics agree that some excess capacity is needed. And, in fact, state regulations require a 15% cushion. California surpasses that mark and is on pace to exceed it by 6 percentage points in the next three years, according to the Western Electricity Coordinating Council, which tracks capacity and reliability. In the past, the group has estimated the surplus would be even higher.

Michael Picker, current president of California's Public Utilities Commission, said the state's excess power supply is a strategic decision to ensure reliability. Loretta Lynch, who held the same position from 2002 to 2005, has been a critic of overbuilding since she chaired the regulatory agency. (Associated Press)

Even the 15% goal is "pretty rich," said Robert McCullough of Oregon-based McCullough Research, who has studied California's excess electric capacity for both utilities and regulators. "Traditionally, 10% is just fine. Below 7% is white knuckle. We are a long way from white-knuckle time" in California.

Contrary to Picker's assertion, critics say, customers aren't aware that too



much capacity means higher rates. "The winners are the energy companies," Lynch said. "The losers are businesses and families."

The over-abundance of electricity can be traced to poorly designed deregulation of the industry, which set the stage for blackouts during the energy crisis of 2000-2001.

Lawmakers opened the state's power business to competition in 1998, so individual utilities would no longer enjoy a monopoly on producing and selling electricity. The goal was to keep prices lower while ensuring adequate supply. Utilities and their customers were allowed to buy electricity from new, unregulated operators called independent power producers.

The law created a new exchange where electricity could be bought and sold, like other commodities such as oil or wheat.

Everyone would benefit. Or so the thinking went.

In reality, instead of lowering electricity costs and spurring innovation, market manipulation by Enron Corp. and other energy traders helped send electricity prices soaring.

That put utilities in a bind, because they had sold virtually all their natural gas plants. No longer able to produce as much of their own electricity, they ran up huge debts buying power that customers needed. Blackouts spread across the state.

State leaders, regulators and the utilities vowed never to be in that position again, prompting an all-out push to build more plants, both utility-owned and independent.

"They were not going to allow another energy crisis due to a lack of generation," said Alex Makler, a senior vice president of Calpine, the independent power producer that owns the Sutter Energy plant not far from Sacramento.

But the landscape was starting to change. By the time new plants began generating electricity, usage had begun a decline, in part because of the economic slowdown caused by the recession but also because of greater energy efficiency.

The state went from having too little to having way too much power.

"California has this tradition of astonishingly bad decisions," said McCullough, the energy consultant. "They build and charge the ratepayers. There's nothing dishonest about it. There's nothing complicated. It's just bad planning."

"

California has this tradition of astonishingly bad decisions.

— Robert McCullough, energy consultant

The saga of two plants — Sutter Energy and Colusa — helps explain in a microcosm how California came to have too much energy, and is paying a high price for it.

Sutter was built in 2001 by Houston-based Calpine, which owns 81 power plants in 18 states.

Sutter Energy Center, now closed, made money only if Calpine Corp. found customers for the plant's power. Other large, natural gas plants in the state also face early closures. (David Butow / For The Times)

Colusa Generating Station opened in 2010. Pacific Gas & Electric will charge ratepayers more than $700 million over the plant's lifespan, to cover its operating costs and the profit guaranteed to public utility companies. (Rich Pedroncelli / AP)

Independents like Calpine don't have a captive audience of residential customers like regulated utilities do. Instead, they sell their electricity under contract or into the electricity market, and make money only if they can find customers for their power.

Sutter had the capacity to produce enough electricity to power roughly 400,000 homes. Calpine operated Sutter at an average of 50% of capacity in its early years — enough to make a profit.

But then Pacific Gas & Electric Co., a regulated, investor-owned utility, came along with a proposal to build Colusa.

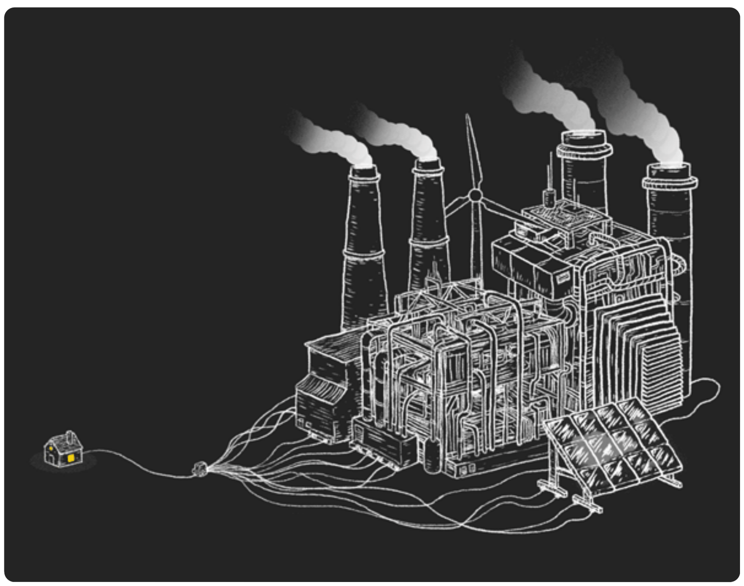
It was not long after a statewide heat wave, and PG&E argued in its 2007 request seeking PUC approval that it needed the ability to generate more power. Colusa — a plant almost identical in size and technology to Sutter — was the only large-scale project that could be finished quickly, PG&E said.

More than a half-dozen opponents, including representatives of independent power plants, a municipal utilities group and consumer advocates filed objections questioning the utility company. Wasn't there a more economical alternative? Did California need the plant at all?

They expressed concern that Colusa could be very expensive long-term for customers if it turned out that its power wasn't needed.

That's because public utilities such as PG&E operate on a different model.

If electricity sales don't cover the operating and construction costs of an independent power plant, it can't continue to run for long. And if the independent plant closes, the owner — and not ratepayers — bears the burden of the cost.



(/projects/la-fi-electricity-capacity-graphic/) (/projects/la-fi-electricity-capacity-graphic/) (/projects/la-fi-electricity-capacity-graphic/) California's energy supply: From blackouts to glut (/projects/la-fi-electricity-capacity-graphic/)

View the interactive graphic (/projects/la-fi-electricity-capacity-graphic/)

In contrast, publicly regulated utilities such as PG&E operate under more accommodating rules. Most of their revenue comes from electric rates approved by regulators that are set at a level to guarantee the utility recovers all costs for operating the electric system as well as the cost of building or buying a power plant — plus their guaranteed profit.

Protesters argued Colusa was unnecessary. The state's excess production capacity by 2010, the year Colusa was slated to come online, was projected to be almost 25% — 10 percentage points higher than state regulatory requirements.

The looming oversupply, they asserted, meant that consumers would get stuck with much of the bill for Colusa no matter how little customers needed its electricity.

And the bill would be steep. Colusa would cost PG&E $673 million to build. To be paid off, the plant will have to operate until 2040. Over its lifetime, regulators calculated that PG&E will be allowed to charge more than $700 million to its customers to cover not just the construction cost but its operating costs and its profit.

Pacific Gas & Electric's Colusa Generating Station has operated at well below its generating capacity — just 47% in its first five years. (Rich Pedroncelli / AP)

The urgent push by PG&E "seems unwarranted and inappropriate, and potentially costly to ratepayers," wrote Daniel Douglass, a lawyer for industry groups that represent independent power producers.

The California Municipal Utilities Assn. — whose members buy power from public utilities and then distribute that power to their customers — also complained in a filing that PG&E's application appeared to avoid the issue of how Colusa's cost would be shared if it ultimately sat idle. PG&E's "application is confusing and contradicting as to whether or not PG&E proposes to have the issue of stranded cost recovery addressed," wrote Scott Blaising, a lawyer representing the association. ("Stranded cost" is industry jargon for investment in an unneeded plant.)

The arguments over Colusa echoed warnings that had been made for years by Lynch, the former PUC commissioner.

A pro-consumer lawyer appointed PUC president in 2000 by Gov. Gray Davis, Lynch consistently argued as early as 2003 against building more power plants.

"I was like, 'What the hell are we doing?' " recalled Lynch.

She often butted heads with other commissioners and utilities who pushed for more plants and more reserves. Midway though her term, the governor replaced her as president — with a former utility company executive.

One key battle was fought over how much reserve capacity was needed to guard against blackouts. Lynch sought to limit excess capacity to 9% of the state's electricity needs. But in January 2004, over her objections, the PUC approved a gradual increase to 15% by 2008.

"We've created an extraordinarily complex system that gives you a carrot at every turn," Lynch said. "I'm a harsh critic because this is intentionally complex to make money on the ratepayer's back."

With Lynch no longer on the PUC, the commissioners voted 5-0 in June 2008 to let PG&E build Colusa. The rationale: The plant was needed, notwithstanding arguments that there was a surplus of electricity being produced in the market.

PG&E began churning out power at Colusa in 2010. For the nearby Sutter plant, that marked the beginning of the end as its electricity sales plummeted.

In the years that followed, Sutter's production slumped to about a quarter of its capacity, or just half the rate it had operated previously.

Calpine, Sutter's owner, tried to drum up new business for the troubled plant, reaching out to shareholder-owned utilities such as PG&E and other potential buyers. Calpine even proposed spending $100 million to increase plant efficiency and output, according to a letter the company sent to the PUC in February 2012.

PG&E rejected the offer, Calpine said, "notwithstanding that Sutter may have been able to provide a lower cost."

Asked for comment, PG&E said, "PG&E is dedicated to meeting the state's clean energy goals in cost-effective ways for our customers. We use competitive bidding and negotiations to keep the cost and risk for our customers as low as possible." It declined to comment further about its decision to build Colusa or on its discussions with Calpine.

Without new contracts and with energy use overall on the decline, Calpine had little choice but to close Sutter.

During a 2012 hearing about Sutter's distress, one PUC commissioner, Mike Florio, acknowledged that the plant's troubles were "just the tip of the proverbial iceberg." He added, "Put simply, for the foreseeable future, we have more power plants than we need."

Colusa, meanwhile, has operated at well below its generating capacity — just 47% in its first five years — much as its critics cautioned when PG&E sought approval to build it.

Sutter isn't alone. Other natural gas plants once heralded as the saviors of California's energy troubles have found themselves victims of the power glut. Independent power producers have announced plans to sell or close the 14-year-old Moss Landing power plant at Monterey Bay and the 13-year-old La Paloma facility in Kern County.

“

> Put simply, for the foreseeable future, we have more power plants than we need.
>
> — Mike Florio, former PUC commissioner

Robert Flexon, chief executive of independent power producer Dynegy Inc., which owns Moss Landing, said California energy policy makes it difficult for normal market competition. Independent plants are closing early, he said, because regulators favor utility companies over other power producers.

"It's not a game we can win," Flexon said.

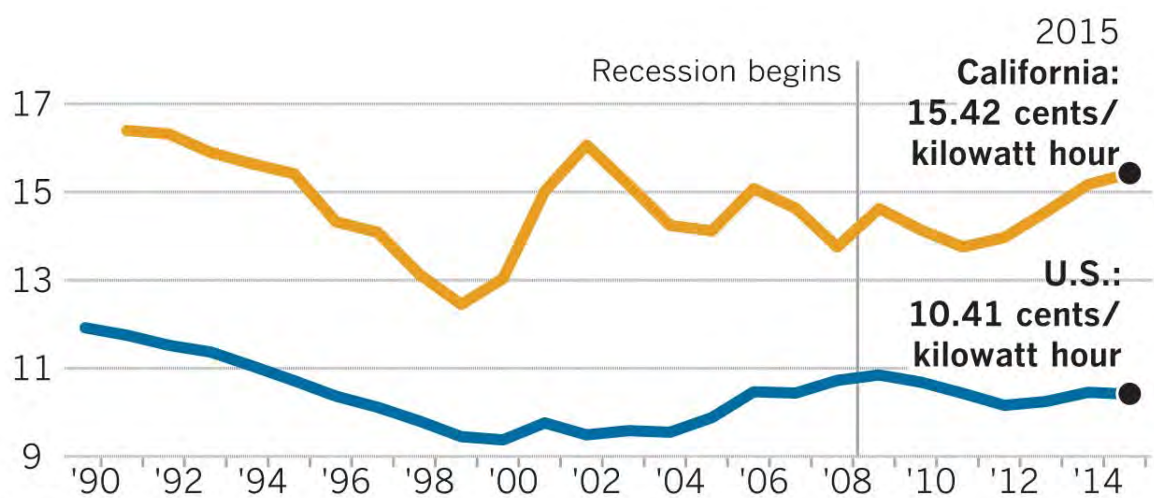
Since 2008 alone — when consumption began falling — about 30 new power plants approved by California regulators have started producing electricity. These plants account for the vast majority of the 17% increase in the potential electricity supply in the state during that period.

Hundreds of other small power plants, with production capacities too low to require the same level of review by state regulators, have opened as well.

Most of the big new plants that regulators approved also operate at below 50% of their generating capacity.

So that California utilities can foot the bill for these plants, the amount they are allowed by regulators to charge ratepayers has increased to $40 billion annually from $33.5 billion, according to data from the U.S. Energy Information Administration. This has tacked on an additional $60 a year to the average residential power bill, adjusted for inflation.

Another way of looking at the impact on consumers: The average cost of electricity in the state is now 15.42 cents a kilowatt hour versus 10.41 cents for users in the rest of the U.S. The rate in California, adjusted for inflation, has increased 12% since 2008, while prices have declined nearly 3% elsewhere in the country.



Note: cost of power figures are adjusted for inflation.
Source: Energy Information Administration
Graphics reporting by Ryan Menezes

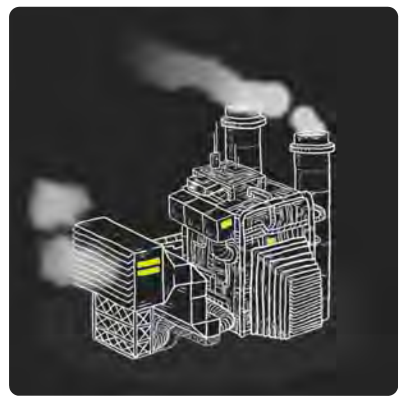
@latimesgraphics

California utilities are "constantly crying wolf that we're always short of power and have all this need," said Bill Powers, a San Diego-based engineer and consumer advocate who has filed repeated objections with regulators to try to stop the approval of new plants. They are needlessly trying to attain a level of reliability that is a worst-case "act of God standard," he said.

Even with the growing glut of electricity, consumer critics have found that it is difficult to block the PUC from approving new ones.

In 2010, regulators considered a request by PG&E to build a $1.15-billion power plant in Contra Costa County east of San Francisco, over objections that there wasn't sufficient demand for its power. One skeptic was PUC commissioner Dian Grueneich. She warned that the plant wasn't needed and its construction would lead to higher electricity rates for consumers — on top of the 28% increase the PUC had allowed for PG&E over the previous five years.

The PUC was caught in a "time warp," she argued, in approving new plants as electricity use fell. "Our obligation is to ensure that our decisions have a legitimate factual basis and that ratepayers' interest are protected."



(/projects/la-fi-electricity-capacity-graphic/)

California's energy supply: From blackouts to glut (/projects/la-fi-electricity-capacity-graphic/)

View the interactive graphic (/projects/la-fi-electricity-capacity-graphic/)

Her protests were ignored. By a 4-to-1 vote, with Grueneich the lone dissenter, the commissioners approved the building of the plant.

Consumer advocates then went to court to stop the project, resulting in a rare victory against the PUC. In February 2014, the California Court of Appeals overturned the commission, ruling there was no evidence the plant was needed.

Recent efforts to get courts to block several other PUC-approved plants have failed, however, so the projects are moving forward.

Contact the reporters (mailto:ivan.penn@latimes.com; ryan.menezes@latimes.com?subject=The Power Boom). For more coverage follow @ivanlpenn (https://twitter.com/ivanlpenn) and @ryanvmenezes (https://twitter.com/ryanvmenezes)

Times data editor Ben Welsh contributed to this report. Illustrations by Eben McCue. Graphics by Priya Krishnakumar and Paul Duginski. Produced by Lily Mihalik

EXHIBIT 2

California Public Utilities Commission

RENEWABLES PORTFOLIO STANDARD

ANNUAL REPORT
NOVEMBER 2017

About this Report

The purpose of this annual report is to comply with Public Utilities Code Section 913.4. Each November, the CPUC is required to report to the Legislature on the progress of California's electrical corporations in complying with the Renewables Portfolio Standard (RPS) program.

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California's

Renewables Portfolio Standard

ANNUAL REPORT

Submitted to the Legislature

November 2017

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TABLES & FIGURES

In compliance with Senate Bill (SB) 1222 (Hertzberg, 2016; as codified in Public Utilities Code Section 913.4[1]), the California Public Utilities Commission (CPUC or Commission) reports to the Legislature each year on the progress of the RPS program. This report describes the progress of the State's electrical retail sellers in complying with the Renewables Portfolio Standard (RPS) Program and shows that:

- California's electrical corporations met the 25% RPS requirement for 2016, and in many cases, substantially exceeded this requirement.[2]
- The large investor-owned utilities (IOU) have executed renewable electricity contracts necessary to exceed 2020's 33% RPS requirement.
- The IOUs' aggregated forecast project they will meet the 2030 RPS requirement of 50% by 2020.
- Community Choice Aggregators (CCA) and the small and multi-jurisdictional utilities (SMJU) report compliance with current RPS requirements, and forecast that they will meet or exceed 2020's 33% RPS requirement.
- The RPS program has helped achieve large reductions in cost for renewable electricity: between 2008 and 2016, the price of utility scale solar contracts reported to the CPUC have gone down 77%, and between 2007 and 2015 reported prices of wind contracts have gone down 47%.[3]

[1] See Appendix B for full text of Public Utilities Code (PU Code) Section 913.4.
[2] Based on filings submitted to the CPUC by retail sellers, they are exceeding RPS requirements with the exception of a few filings by ESPs.
[3] This does not reflect further wind contract price reductions in 2016 or 2017 because of limited new wind contracts reported to the CPUC during that time.

About the Annual RPS Report

Each November, the CPUC reports to the Legislature on the progress and compliance of California's electricity retailers in meeting RPS requirements. Specifically, this report complies with Public Utilities Code 913.4 sub-sections:

(a) Progress on RPS procurement activities;

(b) Details on RPS activities and implementation;

(c) Projected ability to meet RPS under cost limitations;

(d) Status of RPS plans, activities, procurement, and transmission;

(e) Barriers and policy recommendations to achieving RPS; and

(f) Efforts of electrical corporations related to workforce development, training, and diversity.

About the RPS Program

California's ambitious RPS program is jointly implemented and administered by the California Public Utilities Commission (CPUC) and the California Energy Commission (CEC). The RPS program requires the State's Investor-Owned Utilities (IOUs), Community Choice Aggregators (CCAs), Electric Service Providers (ESPs), and Publicly Owned Utilities (POUs) to procure 50 percent of their total electricity retail sales from eligible renewable energy resources by 2030.

The CPUC reviews and approves RPS Procurement Plans and Compliance Reports for the IOUs, CCAs, and ESPs. The CEC oversees RPS compliance for the POUs.[4]

RPS LEGISLATIVE HISTORY

California's RPS program was established in 2002 by Senate Bill (SB) 1078 (Sher) with the initial requirement that 20% of electricity retail sales be served by renewable resources. The program was accelerated in 2006 under SB 107 (Simitian), which required that the 20% mandate be met by 2010.

In April 2011, Governor Brown signed SB 2 (1X) (Simitian), which codified a higher RPS requirement of 33% to be achieved by December 31, 2020.

In 2015, the Governor signed into law SB 350 (De León), The Clean Energy and Pollution Reduction Act of 2015. SB 350 increased RPS requirements to 50% by December 31, 2030.

In addition, SB 350 includes interim RPS targets of 40% by December 31, 2024 and 45% by December 31, 2027, with three-year compliance periods continuing indefinitely thereafter. The 50% RPS requirement is a minimum.

Governor Brown also signed into law in 2015 SB 697 (Hertzberg), which adopted the Public Utilities Commission Accountability Act of 2015 and recasted some of the Commission's RPS reporting requirements.

[4] This report covers only the entities that the CPUC regulates.

The purpose of increasing the level of renewables in the State's energy mix is to provide a range of benefits to Californians, including:

- Reducing greenhouse gas emissions and air pollution;
- Stabilizing electricity rates;
- Diversifying the energy generation portfolio;
- Meeting resource adequacy requirements; and
- Contributing to the reliable operation of the electrical grid.

California's Electricity Retailers

Large Investor-Owned Utilities (IOU)

Pacific Gas and Electric Company
Southern California Edison Company
San Diego Gas & Electric Company

Small and Multi-Jurisdictional Utilities (SMJU)

Bear Valley Electric Service
Liberty Utilities
PacifiCorp

Community Choice Aggregators (CCA)

Apple Valley Choice Energy
CleanPowerSF
Lancaster Choice Energy
Marin Clean Energy
Peninsula Clean Energy
Pico Rivera Municipal Energy
Redwood Coast Energy Authority
Silicon Valley Clean Energy
Sonoma Clean Power Authority

Electric Service Providers (ESP)

Direct access providers of electricity

California's electricity retail sellers, defined as any entity engaged in the retail sale of electricity to end-use customers located within the State, are required to comply with the RPS program. Within the CPUC's jurisdiction, the large IOUs served approximately 75% of the State's retail electricity load in 2016, while the SMJUs, CCAs, and ESPs collectively served the remaining 25%. The POUs serve approximately 20-25% of California's electric load, but are not retail sellers.

An electricity retailer operating in California is generally classified into one of four categories:

- **IOU:** A private enterprise that engages in the generation and distribution of electricity for sale in a regulated market. Customer rates for utilities are set and regulated by the CPUC through a public process that includes stakeholder participation.
- **SMJU:** An electric utility that has a customer base of 30,000, or fewer or that serves customers across multiple states.
- **CCA:** A local government agency that purchases and develops power on behalf of residents, businesses, and municipal facilities within a local jurisdiction.
- **ESP:** A non-utility entity that offers electric service to customers within the service territory of an electric utility.

How the RPS Program Works

The RPS program encourages investment in the development of new utility-scale renewable energy facilities to meet the electrical demands of the State of California. RPS is a market based program where compliance is determined by the quantity of Renewable Energy Credits (REC) acquired (1 REC = 1 megawatt hour (MWh)).

The CPUC's implementation of the RPS program complements the RPS program administered by the CEC, as well as supports California's climate change policies. The CPUC's compliance process is completed after the CEC verifies RPS-eligible procurement from renewable energy facilities.

The CPUC establishes program policy within its RPS rulemaking proceeding and implements legislation through its Commission decisions to ensure that electricity retailers comply with CPUC rules and State law.[5]

The CPUC's responsibilities in the implementation of the RPS program include:

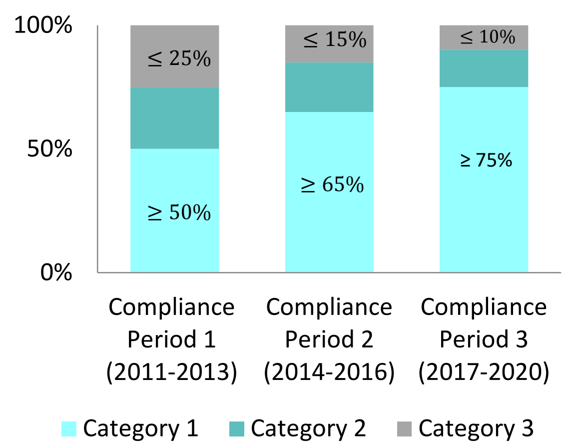
- Setting policy through a public stakeholder process;
- Reviewing and approving each retail seller's RPS procurement plan;
- Reviewing IOU contracts for RPS-eligible energy; and
- Determining and enforcing compliance with procurement targets.

Portfolio Content Category Rules

California's RPS program defines all renewable procurement acquired from contracts executed after June 1, 2010 into one of three portfolio content categories (PCCs):

- **Category 1:** Bundled renewable energy credits (RECs) from facilities with a first point of interconnection within a California Balancing Authority (CBA), or facilities that schedule electricity into a CBA on an hourly or sub-hourly basis.
- **Category 2:** Procurement which bundles RECs with incremental electricity, and/or substitute energy, from outside a CBA. Generally, Category 2 RECs are generated from out-of-state renewable facilities and require a Substitute Energy Agreement that details the simultaneous purchase of energy and RECs from an RPS-eligible facility.
- **Category 3:** Unbundled RECs that do not include the physical delivery of the energy attached to the REC. Generally, Category 3 RECs are associated with the sale and purchase of the RECs themselves, not the energy.

Figure 1: RPS Portfolio Content Category Requirements



[5] The CPUC Rulemaking for the RPS program is currently R.15-02-020.

In addition to complying with RPS procurement requirements and PCC classifications, most retail sellers have specified requirements for the balance or mix of procurement from contracts that are executed after June 1, 2010. Specifically, these retail sellers must procure a minimum level of Category 1 RECs, which increases over the initial three multi-year compliance periods.[6] There is a maximum limit on the amount of Category 3 procurement that may be used in each compliance period, which decreases over the same timeframe.

The PCC requirements are instrumental in determining a retail seller's compliance with the RPS program. Figure 1 depicts the portfolio category limits and how they adjust across compliance periods until 2020, at which point they remain at those limits for each successive compliance period.

Eligible renewable generation facilities may be located anywhere within the Western Electricity Coordinating Council (WECC) region.[7] These facilities are permitted to sell RECs to California retail sellers of electricity to meet their RPS obligations, provided the facility meets all RPS eligibility criteria established by the CEC.

RPS Excess Procurement Rules

RECs that are not used to fulfill RPS obligations in one period may be "banked" and used in subsequent compliance periods. SB 2 (1X) (Simitian, 2011) established the ability for a retail seller to carry over procurement from one compliance period to another. The calculations for excess procurement rely on a combination of the PCC classification of the RECs and whether the RECs are associated with short-term or long-term contracts.

The Commission recently implemented SB 350, which changes the banking rules. Beginning in 2021-2024 compliance period, all excess PCC 1 RECs can be banked, regardless of whether they are associated with short- or long-term contracts; no PCC 2 or PCC 3 RECs can be banked.

[6] See Public Utilities Code § 399.16(c) for additional information.

[7] The WECC region extends from the Canadian provinces of Alberta and British Columbia to the northern part of Baja California, Mexico, and encompasses the 14 western U.S. states in between.

RPS Compliance Requirements

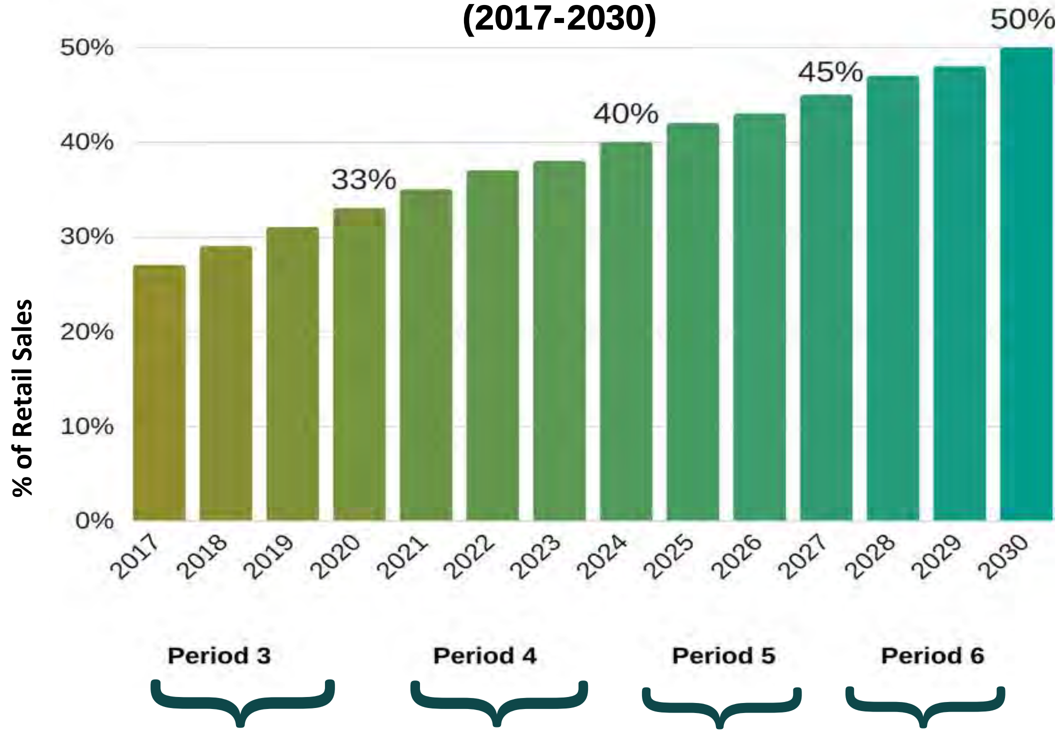
RPS compliance requirements are jointly administered, verified, and enforced by the CPUC and the CEC. Each August 1, retail sellers must submit annual Compliance Reports to the CPUC. The compliance verification process ensures that electricity retailers are on-track to meet a 50% RPS requirement by 2030, via interim compliance period targets.

How RPS Compliance Progress is Measured

The RPS program has six interim compliance periods leading up to 2030 for the purpose of monitoring electricity retail seller progress towards the 50% RPS mandate:

- **2013:** 20%
- **2016:** 25%
- **2020:** 33%
- **2024:** 40%
- **2027:** 45%
- **2030:** 50%

Figure 2: RPS Compliance Period Requirements (2017-2030)



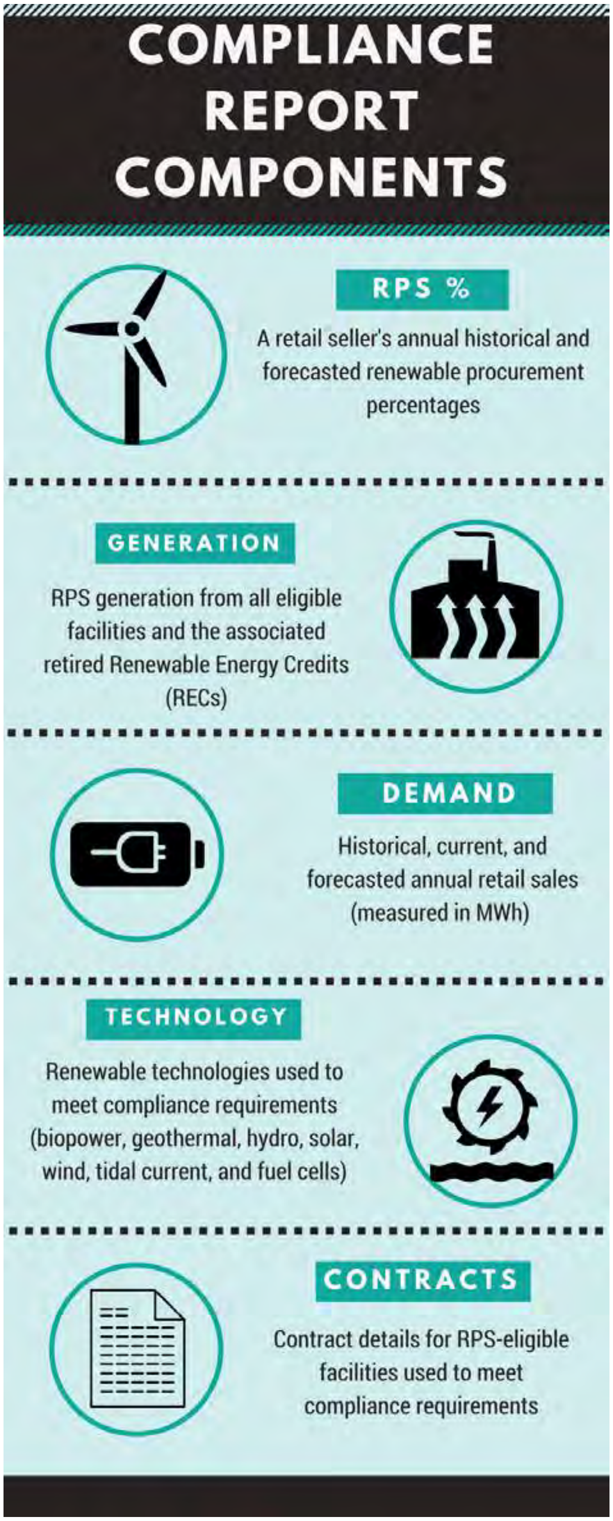
Each year, the CPUC evaluates the utilities' Procurement Plans to review their long-term RPS forecasts and planning mechanisms. The Plans provide information regarding current supplies, projects under development, and forecasted need for additional RPS procurement.

Progress towards the RPS mandate is measured in several ways, including through the analysis of detailed RPS Procurement Plans and Compliance Reports. These documents determine the compliance status of each retail seller in achieving the statewide mandate.

Retail sellers are required to submit annual Compliance Reports to the CPUC that contain historical and forecasted details about their annual renewable procurement. The CPUC evaluates these reports to ensure progress is being made towards the interim targets.

The CPUC works closely with the CEC to ensure that the utilities meet their RPS requirements. Compliance evaluations and official determinations by the CPUC can only take place after the CEC verifies a retail seller's annual REC claims.

The CEC receives reports from energy retailers generated by the Western Renewable Energy Generation Information System (WREGIS) describing the amount of renewable electricity generated by every eligible facility.[8] The CEC analyzes WREGIS reports to determine: eligibility of the facility, the quantity of RECs created from each RPS-eligible facility, and retail sellers' RPS procurement claim to ensure each REC claimed is eligible for compliance with the RPS and is only counted once.



[8] The Western Renewable Energy Generation Information System (WREGIS) is an independent renewable energy tracking system for the region covered by the Western Electricity Coordinating Council (WECC).

Once the CEC has verified the number of RPS eligible RECs, a retail seller can use those RECs to meet their compliance obligations, and those RECs are retired. The CPUC is responsible for reviewing how a retail seller's RPS procurement is classified into PCCs. However, the CPUC can only enforce compliance at the conclusion of the multi-year Compliance Periods.

This chapter uses historical data through December 31, 2016 from the Compliance Reports and the Procurement Plans from the large IOUs, SMJUs, CCAs, and ESPs to illustrate the state of the RPS program. The data presented in this chapter is used by the CPUC to evaluate aspects of RPS procurement, including:

- Procurement progress towards the 50% RPS mandate;
- Current renewable procurement status;
- Renewable portfolio and technology mix;
- Installed renewable capacity; and
- RPS contracting activities.

Large IOUs: Well-positioned to Meet RPS Requirements

All electricity retail sellers were required to serve 25% of their load with RPS-eligible resources by December 31, 2016, as an interim target between compliance periods. The large IOUs surpassed this requirement, as illustrated in Table 1.[9]

Table 1: Actual RPS Procurement Percentages Towards Meeting the 25% Requirement in 2016

PG&E	32.9%
SCE	28.2%
SDG&E	43.2%

Data source: IOU Annual RPS Compliance Filings, August 2017

Table 1 shows that the large IOUs have individually met the 25% target. The IOUs may choose to apply eligible renewable electricity procured in 2016 that is in excess of the RPS requirement to meet their RPS requirements in future compliance periods, or they may sell RECs associated with the excess procurement to third parties.[10]

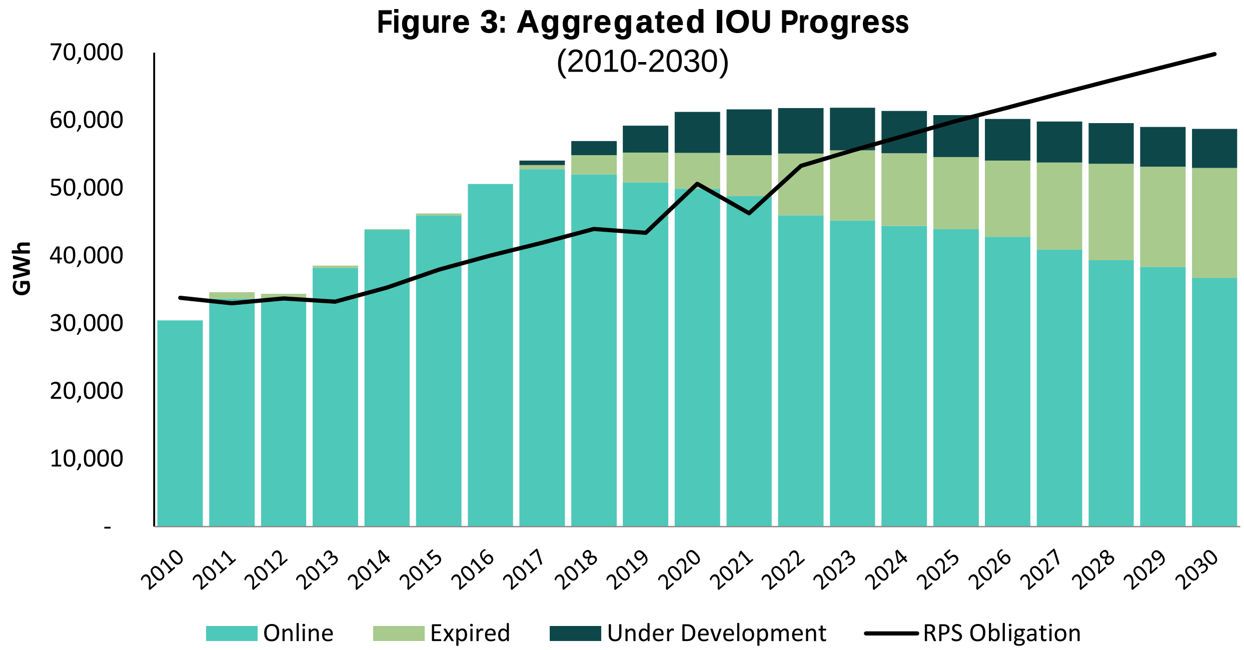
As further described in Chapter 3 under "Excess Procurement," a variety of market conditions have caused the IOUs to be procured beyond their minimum RPS requirements, including the need to hedge against initial program experience with project failure and/or increasing departing load to CCAs.

[9] Based on their annual RPS Procurement Plans, as well as Compliance Reports filed with the CPUC in August 2017, the three large IOUs are well-positioned to meet their procurement targets for the 50% RPS mandate by 2030 using excess procurement through the banking provisions described in Chapter 1.

[10] The three large IOUs forecast having excess procurement for the next five years and are positioned to exceed their RPS obligations (see Table 2).

Figure 3 uses the most current annual data to illustrate the actual and forecasted progress the large IOUs have made toward meeting the 50% RPS mandate on a risk-adjusted basis.[11] The graph shows a forecasted surplus of renewable generation through 2020 and a deficit beginning in 2022.[12] [13] As reported in their Procurement Plans and Compliance Reports, the IOUs forecast that they will meet the 33% RPS requirement by 2020 (see Table 2).[14]

The IOUs forecast that they can meet their RPS requirements by using banked RECs. Given the IOUs have significant excess eligible RPS procurement, they chose not to conduct annual RPS solicitations in 2016 or 2017, nor do they plan to undertake solicitations in 2018 (as described further in Chapter 3).[15]



[11] The data used to create Figure 3 was taken from the IOUs' 2017 Annual RPS Procurement Plans. Generation forecasts from projects "under development" are risk adjusted to account for a certain degree of project failure. Failure rate assumptions are provided by the IOUs in their renewable net short calculation provided with their Draft Annual RPS Procurement Plan that were submitted in July 2017.

[12] Projects that are currently "Under Development" are expected to decrease beginning in 2023 out to 2030 because the project developers and IOUs focus their efforts on the nearer term.

[13] The "Expired" field represents the amount of generation associated with facilities that no longer have a PPA with one of the IOUs. Although this generation is not under contract, there is a possibility that one of the IOUs will re-contract with these facilities.

[14] The RPS obligation decreases from 2020 to 2021 due to the varying Compliance Period timeframe (from three years to four years in a Period).

[15] The IOUs' excess procurement is based on the current forecast of bundled electricity load and additional CCA departures will result in increased amounts of excess.

Table 2 below depicts the large IOUs' actual RPS procurement and forecasted procurement, and shows that the IOUs forecast that they will meet or exceed their 2020 RPS compliance period requirements, and meet the 2030 50% RPS requirement by 2020. The data is aggregated to provide a statewide view of progress and anticipated compliance.[16]

Table 2: Average Large IOUs' RPS Procurement Percentages for PG&E, SCE, and SDG&E in 2016

Actuals						Forecasted			
Compliance Period 1			**Compliance Period 2**			**Compliance Period 3**			
20% Requirement			*25% Requirement*			*33% Requirement*			
2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
20%	20%	23%	28%	30%	35%	38%	42%	47%	50%

Data source: IOU RPS Compliance Reports, August 2017[17]

SMJUs: Demonstrate Need to Procure within the Next Five Years

The SMJUs project that the will meet the current RPS targets for Compliance Period 2 (2014-2016), but have indicated they will need to procure additional resources to meet the post-2020 compliance targets. Table 3 data show an average of two SMJUs' procurement percentages (Liberty and BVES), and does not reflect the procurement of the individual utilities. Both Liberty Utilities and Bear Valley Electric Service (BVES) included their forecasted RPS procurement percentages in their 2017 RPS Procurement Plan and compliance filings.[18]

Table 3: Average SMJUs' RPS Procurement Percentages BVES and Liberty in 2016

Actuals						Forecasted			
Compliance Period 1			**Compliance Period 2**			**Compliance Period 3**			
20% Requirement			*25% Requirement*			*33% Requirement*			
2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
20%	21%	22%	29%	25%	27%	28%	29%	32%	33%

Data source: SMJU RPS Compliance Reports, August 2017

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[16] Each retail seller must file its annual RPS Procurement Plan and Compliance Report. Renewable procurement data is not automatically confidential but may be claimed as such through a formal filing. In the formal confidentiality filing, the retail seller must justify why the information should be treated as confidential by the CPUC. Generally, historical data should be public and individual contracts may be confidential for 3 years from the date that energy deliveries begin. Additionally, retail sellers are allowed to redact forecast information three years forward. See the CPUC's Decision on Confidentiality (D.06-06-066) for more information: http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/57772.PDF.

[17] Note: The forward-looking data (2017-2020) of each IOU is treated as confidential information per D.06-06-066.

[18] PacifiCorp data is not included in Table 3 due to confidentiality rules, as its confidential information could be derived due to public data available from Liberty and BVES.

CCAs: Demonstrate Need to Procure within the Next Five Years

RPS Compliance Reports submitted by Marin Clean Energy (MCE), Sonoma Clean Power (SCP), Lancaster Choice Energy (LCE), Peninsula Clean Energy (PCE) and CleanPowerSF indicate the CCAs have met the current RPS targets. However, their preliminary compliance reports indicate they will need to procure renewable resources to meet the 50% RPS target by 2030. Table 4 provides an average of these CCA's reported procurement percentages.

Table 4: Average CCA RPS Procurement Percentages for MCE, SCP, LCE, PCE, and CPSF in 2016

Actuals						Forecasted			
Compliance Period 1			Compliance Period 2			Compliance Period 3			
20% Requirement			*25% Requirement*			*33% Requirement*			
2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
28%	29%	30%	48%	39%	47%	46%	38%	38%	30%

Data source: CCA RPS Compliance Reports, August 2017

The information provided above is based on the various operational statuses of the CCAs. From 2011 to 2013, Marin Clean Energy was the only CCA in operation. In 2014, Sonoma Clean Power started serving load, and Lancaster choice started serving load in 2015. Accordingly, the CPUC has collected robust data on the CCAs with the longest operational history, given that the other six certified CCAs have only recently begun serving customers. All certified CCAs, have begun executing contracts for new renewable energy projects that will come online within the next five years.

ESPs: Procurement Assessment Unknown Due to Lack of Long-term Forecasting

ESPs are non-utility electricity service providers which currently serve approximately 13% of California's electricity load. Though California's ESPs are required to file both Compliance Reports and Procurement Plans, they do not provide long-term forecasts on their renewable procurement. The forecasted renewable procurement percentages are not a required element of the Compliance Reports and most ESPs do not forecast beyond the current reporting year. Therefore, the CPUC is unable to provide data on the long-term RPS outlook of the ESPs.

The Status of Current Renewable Portfolios

To provide a more detailed view of the status of RPS portfolios, this section describes a variety of perspectives for retail sellers with available information, including renewable resource mix, installed renewable capacity, and contracting activities. Among the retail sellers in California:

- The large IOUs have the most diverse renewable energy portfolio mix;
- The CCAs have a moderately diverse renewable energy portfolio mix; and
- SMJUs have the least diverse portfolio mixes.

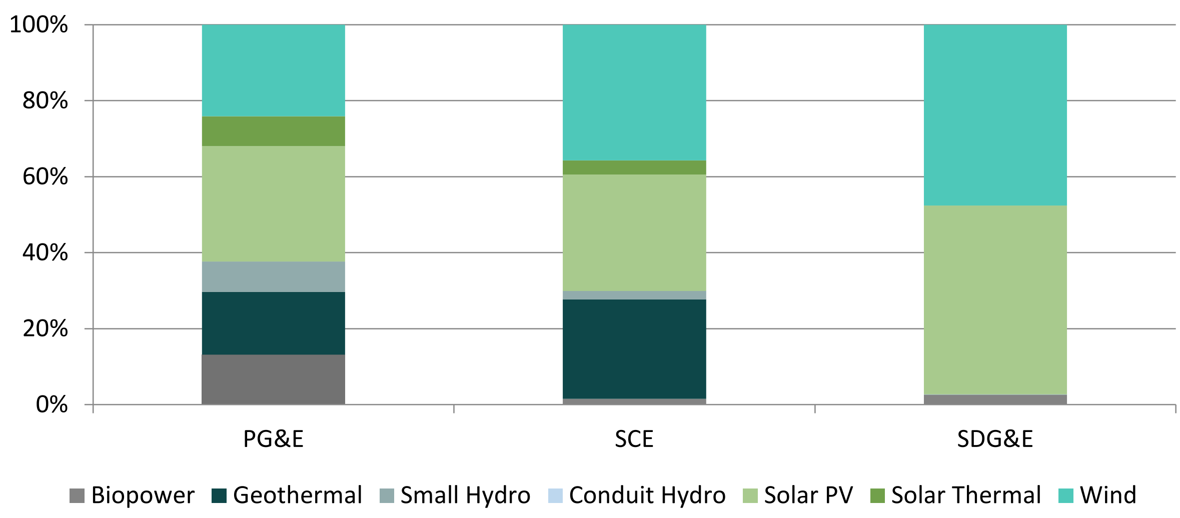
The large IOUs and CCAs have contracted with developers for new renewable facilities to add more capacity to reach the 50% RPS mandate. The SMJUs have been less active in contracting for renewables, but have secured the contracts needed to achieve the RPS requirements.

Renewable Technology Mix

Large IOUs

Since the inception of the RPS program in 2002, the large IOUs have continuously added new renewable technologies to their portfolios in order to satisfy their RPS procurement requirements. The large IOUs contract with a wide range of renewable technologies. Figure 4 shows that as of December 2016, the IOUs have procured diverse renewable energy resources such as wind, solar thermal, solar photovoltaic (PV), geothermal, biopower, and hydroelectric facilities to meet the requirements of the RPS program.[19]

Figure 4: IOU Renewable Portfolio Mixes in 2016



Data Source: IOU Annual Compliance Reports, submitted August 2017

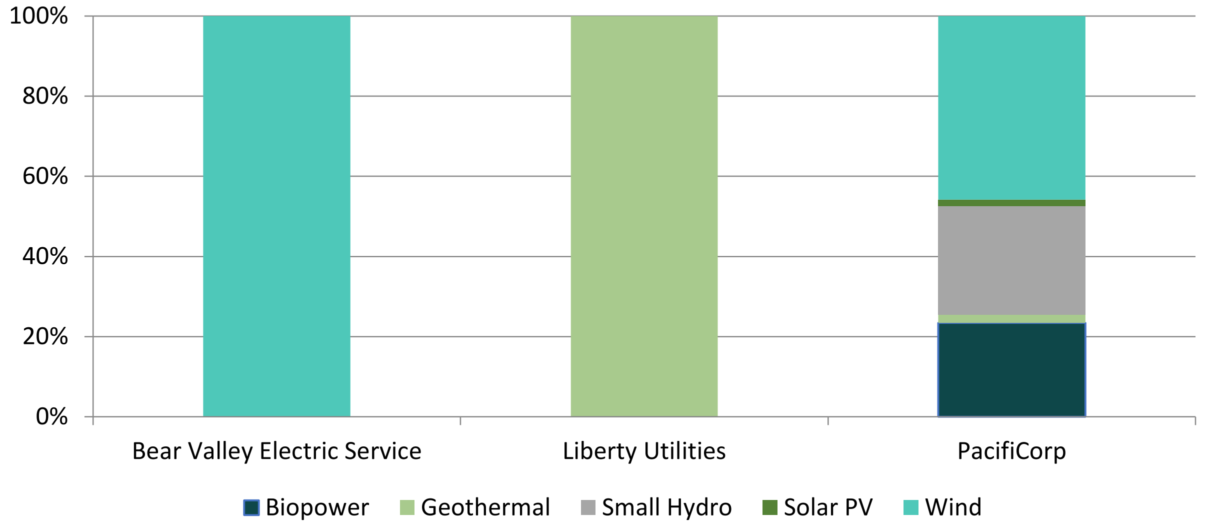
[19] Approximately 1% of SCE's renewable portfolio is comprised of Conduit Hydroelectric technology. The technology category of "Biopower" consists of biomass, biogas, biodiesel, landfill gas, and municipal solid waste.

SMJUs

With the exception of PacifiCorp, the renewable portfolio mixes of California's SMJUs are not as diverse as those of the large IOUs or the CCAs. As Figure 5 shows, Bear Valley Electric Service and Liberty Utilities, respectively, procured one technology each - wind and geothermal - to meet their RPS requirements.

In 2016, PacifiCorp had five technologies in its renewable energy portfolio, with the majority comprised of wind (44%) and biopower (23%).

Figure 5: SMJU Renewable Portfolio Mixes in 2016



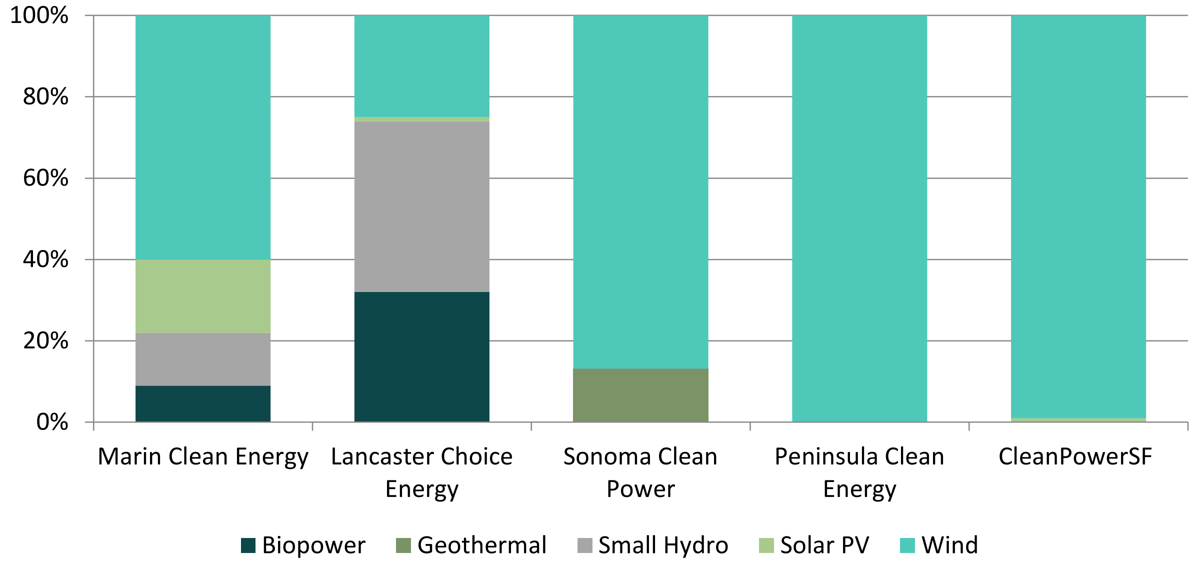
Data Source: SMJUs' Annual Compliance Reports, submitted August 2017

CCAs

Figure 6 illustrates the renewable energy portfolio mixes of the five CCAs that operated in California in 2016. Marin Clean Energy (MCE), Lancaster Choice Energy (LCE), and Sonoma Clean Power (SCP) have been in operation for six, three, and two years, respectively, and have more diverse resource mixes than Peninsula Clean Energy (PCE) and CleanPowerSF. Both PCE and CleanPowerSF began delivering energy in 2016.

In 2016, wind energy resources comprised the majority of MCE, SCP, PCE and CleanPowerSF's renewable portfolios at 60%, 86%, 100%, and 99%, respectively. The majority of LCE's portfolio (74%) consisted of small hydroelectric and biopower facilities.

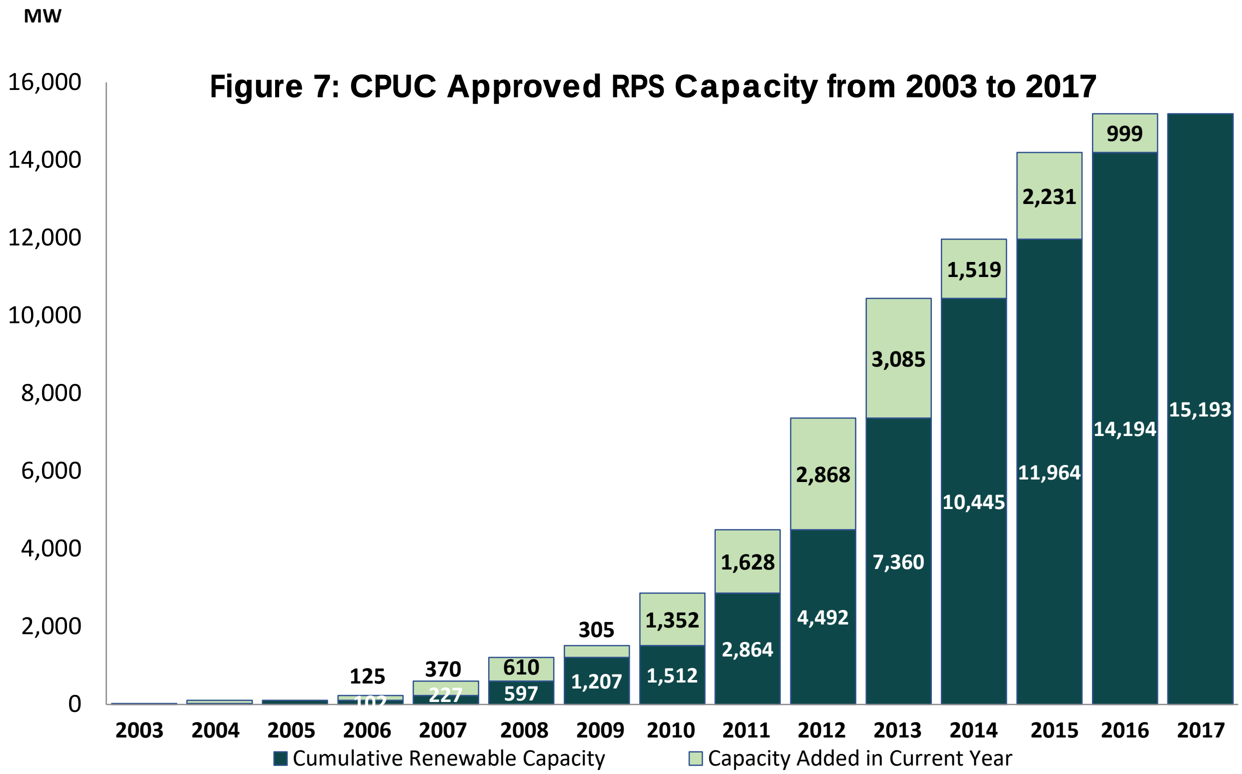
Figure 6: CCA Renewable Portfolio Mixes in 2016



Data Source: CCA Annual Compliance Reports, submitted August 2017

Installed Renewable Capacity

Since 2003, the three large IOUs have installed 15,193 MW of renewable capacity under the RPS program. As of October 2017, 344 MW of new renewable capacity came online. An additional 453 MW of renewable capacity is forecasted to achieve commercial operation in the next two years. The approved RPS capacity described in Figure 7 below includes both in-state and out-of-state facilities, with the majority of the facilities being in-state and solar PV being California's largest in-state renewable resource.



Data source: IOU Project Update Submissions to the CPUC's RPS Contract Database (October 2017)

2016 Renewable Contracting Activities

In 2016, the IOUs collectively executed five BioRAM contracts, three Request for Offer (RFO) contracts, fourteen ReMAT contracts, and four Qualifying Facilities (QF) contracts for a total of 209 MW of new RPS capacity. Table 5 below shows that PG&E executed twelve contracts, six of which were ReMAT contracts. PG&E signed six other contracts, half of which were from RFOs and half that were from QFs. Similarly, SCE executed twelve contracts where eight of them were under the ReMAT program, three were BioRAM, and one was a QF contract. SDG&E signed two contracts, both of which were to fulfill their BioRAM program requirement.[20]

Table 5: Number of Large IOU RPS Contracts Approved by the CPUC in 2016

	PG&E		SCE		SDG&E		Totals	
Procurement Program	Contracts	MW	Contracts	MW	Contracts	MW	**Contracts**	**MW**
BioRAM (Biomass)	0	0	3	67	2	48	**5**	**115**
ReMAT	6	6	8	15	0	0	**14**	**21**
RFO	3	65	0	0	0	0	**3**	**65**
QF CHP	3	7	0	0	0	0	**3**	**7**
QF Standard Contract	0	0	1	1	0	0	**1**	**1**
Totals	12	72	12	83	2	48	**26**	**209**

Data source: IOU Project Update Submissions to the CPUC's RPS Contract Database (October 2017)

2016 Power Purchase Agreement Diversity

While the table above illustrates that BioRAM had the most RPS-eligible MWs procured, the table below shows that ReMAT had the largest proportion of executed contracts based on number of contracts. Table 6 shows that the majority (54%) of the IOUs' executed contracts were from the ReMAT program. In addition, the data show that the smallest percentage (12%) of the RPS contracts originated through RFOs.

Table 6: Percentage of IOU RPS Contracts (2016)

RPS Program	# of Contracts
ReMAT	54%
BioRAM	19%
QF Contracts	15%
RFO/Solicitation	12%

[20] Table 5 illustrates data from the large IOUs, but there were also other RPS contracts signed by the SMJUs, CCAs, and ESPs. Per D.12-06-038, the CPUC collects monthly data from the large IOUs on: RPS projects, including contract details, project development status, technology type, location, capacity, financing status, construction start date, commercial online date, regulatory status, and interconnection details.

Chapter 3 uses data through October 2017 to provide an overview of 2017 RPS activities, describing implementation of the large IOUs' RPS procurement and status:

- Renewable procurement
- Implementation of RPS Legislation
- RPS Compliance and Enforcement

In addition, Chapter 3 describes the 2017 Draft RPS Procurement Plans for the large IOUs, SMJUs, and the CCAs that were submitted in July 2017. Once approved, these Plans will provide guidance for 2018 RPS activities, and beyond.

While the Commission assures that RPS Procurement Plans for the CCAs and ESPs meet required planning criteria, the CPUC has limited jurisdiction over their procurement activities.

2017 RPS Procurement Activities of the Large IOUs

As demonstrated in Chapter 2, the large IOUs are currently long on procurement and are anticipated to meet their 2030 RPS requirements by 2020. Accordingly, the IOUs chose not to hold annual RPS solicitations in 2017.

However, the IOUs were required to procure renewable energy through other RPS programs in order to meet RPS and various other State policy goals. These programs include:

- Renewable Auction Mechanism (RAM)
- Bioenergy Renewable Auction Mechanism (BioRAM)
- Renewable Market Adjusting Tariff (ReMAT)
- Bioenergy Market Adjusting Tariff (BioMAT)

Renewable Auction Mechanism (RAM)

The Renewable Auction Mechanism (RAM) is a simplified, market-based mechanism for renewable distributed generation projects. RAM allows the IOUs to competitively procure RPS-eligible generation via a streamlined procurement process, allowing bidders to set their own price, use a standard contract, and allow IOUs to submit projects to the CPUC through an expedited regulatory review process.

RAM is designed to facilitate quick and simple transactions for projects that meet minimum criteria. Since the inception of the RAM program, the IOUs have held seven auctions, and procured a total of 1,332.5 MW.

The Commission views the RAM program as a targeted and cost-effective means to reduce greenhouse gas emissions, consistent with its integrated resource planning strategies. The initial purpose of the RAM program was to create a simplified market-based procurement process for smaller (<20 MW) RPS generation projects. Subsequently, the size restriction was removed to provide greater flexibility for RAM projects. The IOUs may use their annual RPS Procurement Plan to propose any additional RAM solicitation.

2017 RAM Procurement

Each of the IOUs approached RAM in various ways in 2017:

- **SCE:** did not hold any RAM solicitations given that it met its RAM obligations in 2016.
- **SDG&E:** is expected to meet its RAM obligation through its recent RAM 7 solicitation.
- **PG&E:** executed three contracts and is expected to launch a RAM solicitation by the end of 2017.

RAM Status in 2017

Table 7 below shows that the IOUs are required to procure a balance of 245 MW for the RAM program. SCE has exceeded their RAM requirements, while PG&E and SDG&E are in the process of holding solicitations to meet their remaining requirements.[21]

Table 7: IOU RAM Procurement Status (2017)

RAM Mandated Capacity (MW)	PG&E	SCE	SDG&E	Total
Total RAM Procurement Targets	653	756	165	1,574
RAM Capacity Contracted	515	789	58	1,333
Capacity Remaining	**138**	**0.0**	**107.0**	**245**

Data Source: IOU Draft RPS Procurement Plans, July 2017

Bioenergy Renewable Auction Mechanism (BioRAM)

2017 BioRAM Procurement

The BioRAM program used the RAM process to implement the Governor's October 2015 Emergency Order on Tree Mortality, as well as addressed emergency strategies in SB 859. BioRAM requires the large IOUs to procure 146 MWs of bioenergy from forest fuel in High Hazard Zones (HHZ) from dead and dying trees, in order to aid in mitigating the threat of wildfires.

In early 2017, the Commission approved the final BioRAM contracts, fulfilling the State's emergency orders on Tree Morality that require the IOUs to procure their proportional share of bioenergy from High Hazard Zone (HHZ) forest fuel. In February and April 2017, respectively, the CPUC approved PG&E's executed biomass contracts with the Burney and Wheelabrator facilities, totaling 43 MWs and completing the required BioRAM procurement.[22]

[21] Although PG&E and SDG&E filed requests to eliminate their remaining RAM procurement obligations, the CPUC denied the requests.
[22] SCE and SDG&E executed their required BioRAM contracts in 2016.

2017 BioRAM Status

Table 8 outlines the IOUs' BioRAM contracts that comply with the State's emergency orders. The Governor's Emergency Order resulted in the CPUC's implementation of BioRAM 1 procurement. SB 859 resulted in the CPUC's implementation of BioRAM 2 procurement.

Table 8: Overview of IOU BioRAM Contracts
(All 5-year Terms)

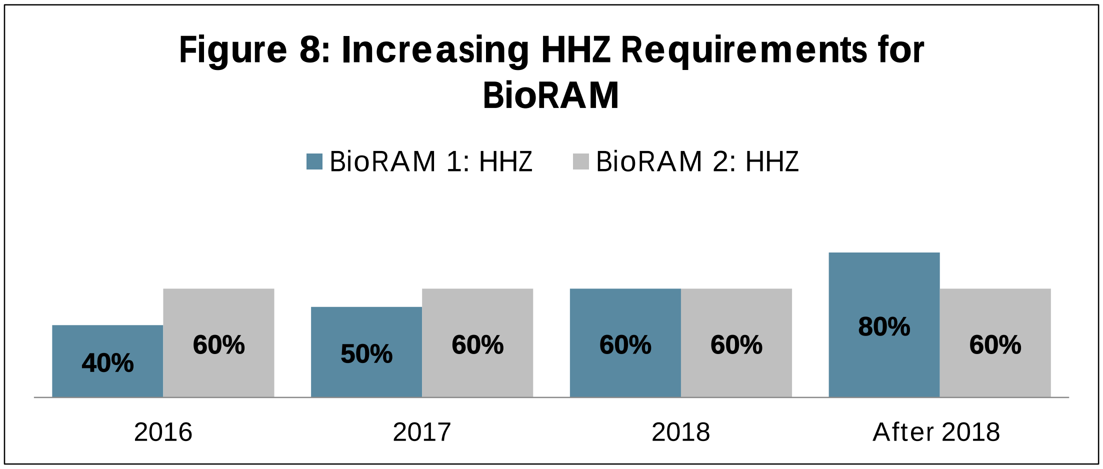
IOU	Facility	Location	BioRAM Procurement (MW)	BioRAM Phase
PG&E	Burney	Burney	29	BioRAM 1
PG&E	Wheelabrator Shasta	Anderson	34	BioRAM 2
SCE	Rio Bravo Fresno	Fresno	24	BioRAM 1
SCE	Rio Bravo Rocklin	Lincoln	24	BioRAM 1
SCE	Ultrapower Chinese Station	Jamestown	18	BioRAM 1
SDG&E	Honey Lake Power Company / Greenleaf	Lassen	24	BioRAM 1
TOTAL			**153**	

Data Source: CPUC analysis of approved contracts, 2017

High Hazard Zone (HHZ) Fuel Requirements for BioRAM:

As figure 8 illustrates, BioRAM contracts are required to achieve assigned HHZ forest fuel usage targets:

- **BioRAM 1 (Governor's Emergency Order):** Starts at 40% and increases to 80% beyond 2018.
- **BioRAM 2 (SB 859):** At least 60% HHZ, with 80% from sustainable forest.



Data Source: Commission Resolutions E-4770 and E-4805

Tracking High Hazard Zone Forest Fuel Requirements for BioRAM:

The IOUs collect quarterly data from the biomass facilities in order to track the amount of bioenergy that is being produced from HHZ forest fuel in the BioRAM contracts. The HHZ requirement is based on an annual calendar year measurement. Table 9 shows the amount of HHZ fuel used in 2017 as part of BioRAM contracts. This data reflects bioenergy from the two facilities currently operating that have collected data, Chinese Station and Honey Lake Power. The Burney facility commenced operation at the end of October 2017. The other three contracted BioRAM projects have not yet commenced delivery.

Table 9: High Hazard Zone (HHZ) Forest Fuel Usage in 2017 from BioRAM 1 Contracts

(Aggregated Statewide)

Total HHZ Used (BDT)	Average % of Total Biomass Fuel from HHZ Fuel
56,951	41.45%

Note: BDT = Bone Dry Tons, which is approximately 1:1 equivalent with MWh

Data Source: CPUC Aggregated Data from IOUs, available as of 10/2/17 - Aggregated due to confidentiality rules

The IOUs are currently in the process of devising their fuel verification processes for BioRAM programs. Verification programs will examine the self-reported data from biomass facilities, and ensure that they are meeting their assigned HHZ fuel requirements on an annual basis, at the end of each calendar year.

BioRAM Non-Bypassable Charge Proceeding

SB 859 directed that the costs from BioRAM procurement be allocated to all customers, including CCAs and ESPs, given that all customers benefit from preventing wildfires. In 2017, the CPUC began the process to establish the mechanism to allocate costs from these programs to customers.

Feed-in Tariff (FIT) Programs

A Feed-in Tariff (FIT) program is a policy mechanism designed to accelerate investment in small, distributed renewable energy technologies. The goal of Feed-in Tariff programs is to offer long-term contracts and price certainty that aid in financing renewable energy investments. The RPS program has two FIT programs:

- Renewable Market Adjusting Tariff (ReMAT)
- Bioenergy Market Adjusting Tariff (BioMAT)

Both programs have capacity procurement mandates established by the Legislature, which are generally allocated to each IOU based on their proportionate share of statewide load served.

Renewable Market Adjusting Tariff (ReMAT)

The ReMAT is a large IOU program that provides market-based adjusting prices for small RPS-eligible facilities (generating up to 3 MW) to sell renewable electricity to utilities under standard terms and conditions.

The ReMAT program was established by SB 32 (Negrete McLeod, 2009) and SB 2 (1x) (Simitian, 2011) and commenced in 2013 offering a fixed-price standard contract to export electricity to California's three large IOUs. The ReMAT program replaced California's original FIT program established by AB 1969 (Yee, 2006) in order to expand the program and increase eligible project size from a maximum of 1.5 MW to up to 3 MW. Recently, AB 1979 modified the program to increase the maximum project capacity to 4 MWs for conduit hydroelectric facilities, if they deliver no more than 3 MW.

IMPLEMENTATION OF AB 1979

In August 2017, the CPUC implemented AB 1979 (Bigelow, 2016) with decision D.17-08-021.

This decision creates ReMAT eligibility for a conduit hydroelectric generation facility of up to 4 MW in capacity, if the facility:

- **was operational as of January 1, 1990;**
- **complies with CPUC and other interconnection rules; and**
- **delivers no more than 3 MW to the grid at any time.**

As a result of AB 1979, conduit hydropower facilities that originally intended to only provide municipal water are now able to leverage their power generating capability.

2017 ReMAT Procurement

In 2017, PG&E procured six ReMAT contracts totaling 6.2 MWs. One of these was a new solar PV project, and the remaining five are existing small hydropower projects. SCE procured three new solar PV projects, totaling 9 MWs. SDG&E did not procure any new ReMAT projects.

ReMAT Program Status

SCE has recently reached the procurement level where, under the program rules, its ReMAT program could be suspended at the end of 2019. SDG&E has suspended its program and therefore SDG&E did not procure any new ReMAT projects. PG&E has the largest amount of capacity remaining at 122 MW.

The IOUs have collectively procured 255.7 MW out of their total 493.6 MW ReMAT requirement. As of the September 2017 program period, the IOUs have procured these proportions of their assigned ReMAT capacity mandate:

- PG&E: 44%
- SCE: 60%
- SDG&E: 47%

Table 10 below provides an overview of the progress that each IOU has made toward their ReMAT capacity mandate from the program's inception in 2013 to present. The ReMAT program has a total of 238 MW of capacity remaining.

Table 10: ReMAT Mandated Allocations Per Large IOU (MW)

	PG&E	SCE	SDG&E	Totals
Total ReMAT Procurement Requirement	219	226	49	**494**
ReMAT Capacity Contracted	97	136	23	**256**
Capacity Remaining	**122**	**90**	**26**	**238**

Data source: CPUC RPS Contract Database, September 2017

Bioenergy Market Adjusting Tariff (BioMAT)

The Bioenergy Market Adjusting Tariff (BioMAT) is a Feed-in-Tariff program created by SB 1122 (Rubio, 2012), which added an additional 250 MW of RPS-eligible procurement for small-scale bioenergy projects up to 3 MW. Modeled after the ReMAT program using a fixed-price standard contract, BioMAT allocates procurement to the distinct bioenergy areas of Biogas, Agriculture, and Forest.

The goal of the BioMAT program is to promote a competitive market with a simple procurement mechanism for bioenergy developer entrants.

2017 BioMAT Procurement

Biogas Category: The Biogas category yielded contracts at the program starting price of $127.72/MWh. Since that time, four biogas contracts have been executed for a total of 7.4 MW, with each IOU having at least one biogas contract. Three biogas contracts were signed in 2017, totaling to 5.85 MW. These contracts were executed at the program price of $127.72/MWh and are expected to come online in mid-2019.

IMPLEMENTATION OF AB 1923

On August 28, 2017, the CPUC issued a decision (D.17-08-021) implementing a portion of AB 1923 (Wood, 2016), which expanded the eligibility of market participants by allowing a biomass facility of up to 5 MW in nameplate capacity to participate in BioMAT if it:

- **complies with CPUC and other interconnection rules; and**
- **delivers no more than 3 MW to the grid at any time.**

In October 2017, the CPUC issued a Ruling to implement the remaining portion of AB 1923. This phase will update BioMAT rules so that BioMAT projects can connect to the existing transmission system in order to increase developer opportunities, increase system efficiencies, and reduce interconnection costs.

Agriculture Category:

This category consists of the Dairy and Other Agriculture sub-queues. From August 1 – September 30, 2017, dairy digester developers accepted a price of $187.72/MWh, totaling 3 MWs. This program period queue did not meet the price adjustment trigger. Accordingly, the price will remain at $187.72/MWh during the October 1 – November 31, 2017 program period.

Forest Category:

For the October 1, 2017 program period, forest biomass developers accepted a price of $199.72/MWh, totaling 5 MWs. Given the number of developers in the queue, the price in this category will remain at $199.72/MWh for a second period. When the bid price remains at this level for two consecutive periods (November 1, 2017), it will trigger a CPUC Energy Division investigation pursuant to program rules adopted in D.14-12-081.

BioMAT Program Status

The BioMAT program launched in February 2016 and has resulted in few contracts, as developers appear challenged by various high costs to entry. Given there are few interested parties in the program queues, the market price has only adjusted upward in the Agriculture and Forest categories, and remained stagnant in the Biogas category.

Table 11: Assigned BioMAT Targets and MWs Achieved

BioMAT Category	BioMAT MW Allocation	MW Contracted
Biogas	110	7.4
Dairy/Agriculture	90	3.0*
Forest	50	5.0*
Total	**250**	**15.4**

Data source: CPUC RPS Contract Database, 2017

**Contracts are not yet executed*

RPS Program Compliance and Enforcement

In 2017, the CPUC implemented and administered RPS Compliance Rules for California's retail sellers of electricity subject to CPUC jurisdiction, which include the large IOUs, SMJUs, CCAs, and ESPs. In August 2017, these entities were required to submit annual Compliance Reports describing their progress towards the State's 50% RPS mandate. The CPUC has begun reviewing retail sellers' 2016 compliance reports.[23]

RPS Program Enforcement Process

The CPUC is responsible for establishing RPS enforcement procedures for retail sellers of electricity and imposing penalties for non-compliance with the RPS program.

In 2017, the CPUC began to revise the existing RPS enforcement framework to comply with SB 350. The Commission expects to issue a decision in 2018 implementing SB 350 mandated changes to the RPS enforcement process. The upcoming decision will be the third decision in a series of SB 350 implementation decisions. It will include the process by which retailers may seek a waiver of some, or all, of their RPS obligations, as well as a "schedule of penalties," as directed by SB 350.

Once notice is given to retail sellers who are deemed non-compliant with their RPS procurement obligations for a compliance period, current statute allows them to request a waiver for the penalty if they can demonstrate any of the following conditions:

- Inadequate transmission capacity;
- Delays caused by permitting or interconnection issues;
- Unanticipated curtailment of eligible renewable resources; or
- Unanticipated increase in retail sales due to transportation electrification.

CHANGES TO THE RPS PROGRAM MANDATED BY SB 350

WAIVER CONDITIONS

SB 350 added conditions that could justify a waiver of a retail seller's RPS requirements, which include:

- Unanticipated curtailment of eligible RPS resources, if the waiver would not cause an increase in GHG emissions; or

- Unanticipated increase in retail sales due to transportation electrification (Pub. Util. Code § 399.15).

In future compliance periods, parties may assert these additional justifications for a waiver request, which will be ruled upon within the RPS proceeding.

LONG-TERM CONTRACTING REQUIREMENTS

Beginning in 2021, SB 350 requires retail sellers to demonstrate that 65% of their procurement comes from long-term contracts. A long-term contract is defined as a contract lasting 10 or more years.

EXCESS PROCUREMENT

The CPUC determined that, beginning in the 2021-2024 Compliance Period, only Category 1 RECs can be banked. Category 1 RECs primarily include renewable generation that has a first point of interconnection in California and can be banked whether procured with short or long-term contracts.

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[23] See Chapter 2 for an overview of progress for RPS goals.

2017 Draft RPS Procurement Plans

California's Renewable Portfolio Standard (RPS) program, requires that electricity retail sellers file annual RPS Plans to assist the CPUC, stakeholders, and California in monitoring renewable procurement to ensure that the State is on-track to meet its renewable energy goals. The RPS Plans provide the CPUC with an overview of the status of RPS procurement and generally describe both the need for additional renewable resources and the actions proposed to achieve those resources.

IMPLEMENTATION OF RPS PROCUREMENT REVISIONS MANDATED BY SB 350

In June 2017, the Commission implemented revised RPS compliance requirements established in SB 350 (D.17-06-026), requiring new standards commencing in the 2021-2024 Compliance Period:

- Retail sellers must demonstrate that 65% of their procurement comes from long-term contracts; and

- Portfolio Content Category (PCC) 1 RECs can be banked, in order to be used or sold in the future. PCC 1 RECs include renewable generation that has a first point of interconnection in California and can be the result of either short or long-term contracts.

These updates to RPS procurement criteria promote the development of new renewable resources that will be used to both increase eligible renewable facilities in the State and reduce greenhouse gas emissions.

Accordingly, each year, the CPUC approves RPS Procurement Plans for the large IOUs and SMJUs. While the CPUC also requires CCAs and ESPs to submit RPS Plans, the CPUC has limited oversight of such procurement activities as solicitations, offer evaluations, and contract approvals. The CPUC's role is to review the Plans of the CCAs and ESPs to ensure that they comply with the CPUC's RPS Plan requirements.

This section provides an overview of key issues presented in the 2017 RPS Draft Procurement Plans by the large IOUs, SMJUs, CCAs, and ESPs.

CPUC RPS Plan Guidelines

The CPUC issues guidance each year, prior to the retail sellers submitting their annual RPS Procurement Plans. In May 2017, the CPUC issued a Ruling with a detailed list of criteria that the utilities must address in their 2017 RPS Plans. These Plans must address the 14 point criteria listed on the table below.

In its decision D.16-12-044, the Commission established key criteria for guiding the development of RPS Procurement Plans.

RPS Procurement Plan Guidance	
Criteria	**Description**
1. Assessment of RPS Portfolio Supplies and Demand	The supply assessment details the retail seller's RPS portfolio and technology mix and the percentage of power served with renewable resources. The demand assessment focuses on retail sales and annual procurement need.
2. Project Development Status Update	Update of development of RPS-eligible resources currently under contract. These resources may be either in development, under construction, or online.
3. Potential Compliance Delays	Rationale for potential delays in achieving compliance with the RPS program. These reasons could include various obstacles for project developers such as securing project financing or interconnecting projects to the electricity grid.
4. Risk Assessment	Evaluation of risks associated with retail sales, generation, project failure, curtailment events, and project delays.
5. Quantitative Information	Quantitative information, such as retail sales forecasts, renewable net short calculations, annual procurement percentages and forecasts, failure percentages, expired contracts, and RECs generated from online and terminated projects.
6. "Minimum Margin" of Procurement	Analysis of information on minimum margin of procurement, defined as the minimum amount of renewables needed to address anticipated project failure or delay.
7. Bid Solicitation Proposals, Including Least-Cost Best-Fit Methodologies	Detail bid selection protocol for procuring additional RPS resources, which includes Least-Cost Best-Fit methodologies used to evaluate new projects.
8. Workforce Development	Details required from project developers to assess how much employment growth would happen during the construction and operation of a new project.
9. Disadvantaged Communities (DACs)	Detail questions for project developers about how the project will impact disadvantaged communities, including the location of the project in proximity to DACs and how the proposed facility will provide benefits to adjacent DACs.
10. Consideration of Price Adjustment Mechanisms	Include perspective on price-adjustment mechanisms in contracts and evaluate what impacts they will have on ratepayers.
11. Curtailment Frequency, Costs, and Forecasting	Detail curtailment activities (e.g., economic curtailment) and how curtailment has affected RPS planning and compliance.
12. Expiring Contracts	Detailed information on expiring RPS contracts.
13. Cost Quantification	Annual summary of actual and forecasted RPS procurement costs and generation by technology type.
14. Safety Considerations	Information on RPS contract provisions related to safety of a facility's operations, construction, and decommissioning, including general operation safety procedures, annual capacity and reliability testing, best industry practices, performance testing, and reporting requirements for all safety related incidents that occur onsite.

Large IOU RPS Plans

On or before July 21, 2017, the IOUs submitted their Draft 2017 RPS Plans to the CPUC. The following sections describe key issues addressed by the IOUs in their RPS Plans. See Chapter 6 for more information on challenges the utilities face in implementing their RPS Plans.

IOU Procurement Assessment

The large IOUs all show long RPS positions and are forecasted to have significant REC bank balances going forward, and as a result are expected to exceed their 2030 RPS targets. A long RPS position means a retail seller procures more energy from RPS-eligible resources than is required under the RPS procurement rules. Accordingly, none of the IOUs propose to hold general RPS solicitations in 2018.

Because of PG&E's long position in meeting RPS goals, in 2017 it held a REC sales solicitation and contracted to sell over 2 million MWh of energy and RECs to 3 Phases Renewables Inc., Direct Energy Business Marketing, LLC, EDF Trading North America, LLC, Exelon Generation Company, LLC, and Peninsula Clean Energy Authority. In 2018, all three IOUs propose additional REC sales in response to their long RPS positions.

Curtailment

The IOUs' RPS Plans describe curtailment as a possible risk to meeting their RPS obligations because the resources might not generate as much RPS-eligible energy as originally forecasted. Curtailment occurs when there is an oversupply of generation or congestion on the grid. The IOUs are preparing for this risk by forecasting expected renewable curtailment in the future, holding long RPS positions, and (since 2011) including economic curtailment terms in executed or amended contracts.

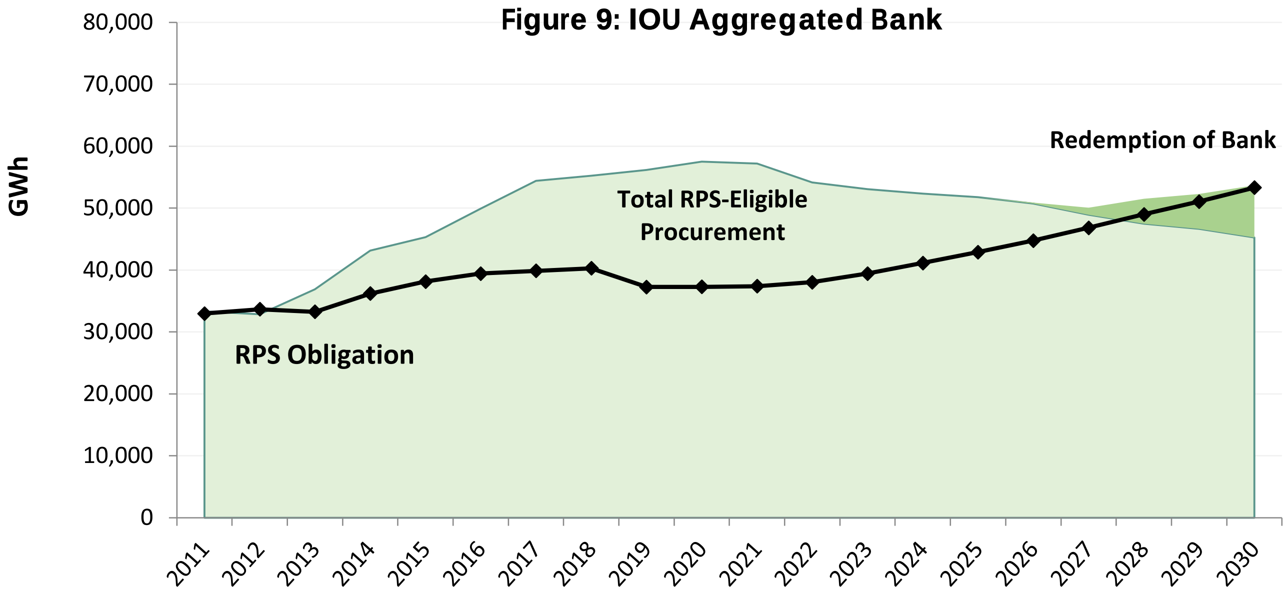
The addition of economic curtailment terms to RPS contracts allows the IOUs to respond to CAISO price signals. The benefits of economic curtailment include both avoided costs and cost savings. Day-ahead curtailments avoid costs of paying negative market prices, which require schedulers or generators to pay to generate. Real-time curtailments capture market opportunity costs (i.e., IOUs get paid to curtail).

Excess Procurement

Initially, the IOUs procured more renewables than necessary in order to hedge against potential RPS shortfalls due to high project failure rates. In addition, excess procurement resulted from market conditions such as the 2008 recession, successful energy efficiency strategies, and renewable energy deployment that benefitted from federal tax incentives. More recently, load migration from IOUs to CCAs has served to further increase the IOUs' long RPS positions.

As described in Chapter 1, retail sellers may bank excess RPS to meet future requirements. The IOUs are forecasted to accumulate significant banks going forward, and therefore, the IOUs have forecasted no need for incremental procurement of RPS-eligible resources until after 2030.

Figure 9 below shows the IOUs' potential aggregate bank accumulation and use of their bank. Bank balance forecasts by individual IOUs are confidential. Accordingly, this data has been aggregated in order to present a statewide view showing that the IOUs are on-track to meet their RPS obligations. In addition, Figure 9 shows the IOUs exhibiting a need for incremental RPS-eligible resources beginning in 2027, and how that need could be met through application of the bank through 2030.



Data source: CPUC's Integrated Resource Planning Modeling Results, E3 Modeling, 2017

Least-Cost Best-Fit Methodology

In order to ensure that the IOUs procure cost-effective resources that most closely match the need of each IOU's portfolio,[24] the Commission adopted criteria for the ranking and selection of Least-Cost Best-Fit (LCBF) renewable resources on a total cost basis.

Accordingly, each IOU in its RPS Plan must propose a LCBF methodology that meets the requirements articulated by the Commission and describes how renewable energy offers will be valued and evaluated, using both quantitative and qualitative criteria.

- **Quantitative Valuations:** May include criteria such as energy cost, congestion cost, locational preference, and transmission costs.
- **Qualitative Valuations:** May include criteria of resource diversity and benefits to disadvantaged communities.

The Commission then approves the LCBF methodologies through the RPS Plans, and the IOUs apply their methodologies to bids within the RPS solicitations. The Commission has given the IOUs substantial flexibility to develop their own individual LCBF methodologies, provided that a transparent rationale is offered to the CPUC and stakeholders.

The draft 2017 RPS Plans contained minimal revisions to the IOUs' LCBF methodologies because the IOUs do not propose to hold annual RPS solicitations in 2018. PG&E and SDG&E submitted revised time-of-delivery factors and SCE proposed to use an Effective Load Carrying Capacity ("ELCC") methodology to calculate Resource Adequacy benefits.

In the past several years, both the Commission and parties to the RPS proceeding have noted a need to revisit the LCBF methodologies. Chapter 4 provides more details on plans for LCBF reform.

Disadvantaged Communities

SB 2 (1X) (Simitian, 2011) requires the IOUs to take environmental justice considerations into account by giving preference to RPS bids that provide environmental or economic benefits to disadvantaged communities (DACs).

In their RPS Procurement Plans, the IOUs propose to collect information from bidders concerning a proposed project's expected benefits for DACs. The information collected from the project bidder is focused on the economic and environmental effects of a new project or facility on DACs. This qualitative information will then be taken into consideration in the LCBF evaluation of RPS bids.

[24] As required by Public Utilities Code 399.13(a).

SMJU RPS Plans

As described in Chapter 1, SMJUs are utilities with fewer than 30,000 customers. The SMJUs include PacifiCorp, Liberty Utilities, and Bear Valley Electric Service (BVES). SMJUs are subject to Pub. Util. Code §§ 399.17 and 399.18, and must meet a smaller subset of the RPS Plan requirements (e.g., they are not required to submit information on expiring contracts).

Further, the RPS procurement requirements allow these retail sellers to meet their procurement obligations without regard to the RPS portfolio content category limitations (PCC). Therefore, new procurement for these SMJUs has consisted of unbundled PCC 3 RECs.

Bear Valley Electric Service

BVES submitted its Draft RPS Plan on July 20, 2017. Currently, a 2013 REC-only contract with Avangrid Renewables, LLC fully satisfies BVES's RPS requirements. BVES stated in its RPS Plan that it is seeking to procure cost-effective bundled RECs to ensure ongoing, long-term RPS compliance. BVES is currently engaged in a Request for Proposals (RFP) for approximately 3 MW of RPS-eligible generation.

Liberty Utilities

Liberty submitted its Draft 2017 RPS Plan on July 21, 2017. Liberty currently serves its load through a combination of utility-owned resources and has a power purchase agreement for PCC 3 RECs with Sierra Pacific Power Company/NV Energy. In 2017, Liberty's 50 MW Luning Solar Project went online. Liberty has also requested CPUC approval to acquire the Turquoise Solar Project to displace additional RPS-eligible energy NV Energy would have provided.

PacifiCorp

PacifiCorp is a multi-jurisdictional utility for RPS purposes. PacifiCorp is permitted to use an Integrated Resource Plan (IRP) prepared for regulatory agencies in other states to satisfy its annual California RPS Procurement Plan requirement so long as the IRP complies with the requirements specified in Pub. Util. Code § 399.17(d). PacifiCorp prepares its IRP on a biennial schedule, filing its plan with the Commission in odd numbered years. It files a supplement to this plan in even numbered years. PacifiCorp filed its 2017 IRP with the Commission on April 4, 2017, and its "on-year" supplement to its 2017 IRP on May 4, 2017. Consequently, PacifiCorp did not file a comprehensive supplement this year.

Community Choice Aggregator (CCA) RPS Plans

CCAs must submit annual RPS Plans to the CPUC and meet the same RPS compliance requirements as investor-owned utilities. On or before July 21, 2017, the CPUC received Draft RPS Plans from all CCAs currently registered with the CPUC. As indicated in their RPS Plans, four of the nine CCAs (Apple Valley, Pico Rivera, Redwood Coast, and Silicon Valley) have begun to serve electricity load in late 2017.

CCA Procurement

The 2017 CCA RPS Procurement Plans forecast that all of the operational CCAs are projected to meet or exceed RPS procurement obligations over the long-term planning horizon (ten or more years). Table 12 below shows that the forecasted 2017 RPS positions of all CCAs in operation vary between a position of 26% and 67%. When the new long-term contracting requirement goes into effect in 2021, it is anticipated that drastic fluctuations in RPS positions will be reduced from year to year, as facilities come online and stay contracted for longer periods of time.

Table 12: Annual RPS Position of CCAs (%)

Online Date	CCA	Actuals	Forecasted	
		2016	2017	2018
2010	Marin Clean Energy	55%	67%	54%
2014	Sonoma Clean Power	36%	43%	46%
2015	Lancaster Choice Energy	39%	26%	26%
2016	Peninsula Clean Energy	59%	51%	29%
2016	CleanPowerSF	45%	44%	32%
2017	Apple Valley Choice	No Data	32%	30%
2017	Pico Rivera	No Data	50%	25%
2017	Redwood Coast	No Data	33%	16%
2017	Silicon Valley	No Data	50%	42%

Data Source: RPS Procurement Plans and Compliance Reports (2017)

CCA Renewable Development

In 2016-2017, Marin Clean Energy (MCE), Lancaster Choice Energy (LCE), and Sonoma Clean Power (SCP) executed contracts which allowed 10 new in-state renewable projects to be financed, built, and brought online. The technologies of these new renewable projects include solar, wind, and biogas. All new projects have long-term contracts ranging from 12 to 25 years in length and will be located in California.

As of September 2017, these three CCAs have a large portion of their renewable generation located in California, with an average of 71% of facilities being located in-state. The generation located in California primarily includes wind, solar, biomass, and geothermal, as well as small and large hydroelectric facilities. MCE has the highest amount of in-state RPS generation with roughly 87% of its total coming from California facilities. SCP and LCE procure approximately 70% and 55%, respectively, of their RPS generation from in-state facilities.

The CCAs of MCE, LCE, SCP, and Peninsula Clean Energy have a total of nine new facilities under contract, which are set to become operational in 2018-2021. As Table 13 shows, the nine new facilities will be comprised of wind and solar projects, totaling 768 MW of new capacity.

Table 13: New Renewables Projects with CCA Contracts
Online Date: 2018-2021

Technology Type	# of Projects	# of MW
Solar (Power Purchase Agreement)	6	555
Wind (Power Purchase Agreement)	3	213
TOTAL	**9**	**768**

Data source: CCA RPS Procurement Plans, 2017

Apple Valley Choice, Pico Rivera, and Redwood Coast Energy have only entered into contracts with facilities that are already in commercial operation. Silicon Valley Clean Energy has entered into one utility-scale contract for a solar facility set to come online in early 2018.

RPS Plan Implementation Schedule

The Commission anticipates issuing a decision on the Draft 2017 RPS Procurement Plans by the end of 2017. The decision will either approve the utilities' proposed RPS Plans or order them to make modifications. Once the CPUC approves the RPS Procurement Plans, the IOUs can commence implementation. The Commission will initiate the next cycle of RPS Plans in the first half of 2018.

Summary of Accomplishments

November 2016	▪ BioRAM Contracts Executed / Approved ▪ PG&E contracted a 1.6 MW municipal bioenergy project under the BioMAT program
December 2016	▪ CPUC approves 2016 RPS Procurement Plans ▪ CPUC adopts D.16-12-040 implementing SB 350's new RPS requirements and compliance periods
January 2017	▪ PG&E contracted 1.4 MW of existing small hydro under the ReMAT Program
February 2017	▪ CPUC approves PG&E BioRAM contract for Burney ▪ IOUs begin offering monthly BioMAT contracts for forest biomass projects
March 2017	▪ PG&E contracted a 0.6 MW existing small hydro project under the ReMAT Program
April 2017	▪ CPUC approves PG&E BioRAM contract for Wheelabrator Shasta
May 2017	▪ CPUC issued RPS Plan Assigned Commissioner/Administrative Law Judge Ruling providing guidance for 2017 RPS Procurement Plans and proposal for RAM procurement ▪ PG&E contracted a 3 MW solar PV project under the ReMAT Program
June 2017	▪ CPUC approves SCE RPS contract for 125 MW Maverick Solar project (Resolution E-4851) ▪ CPUC holds Pre-Hearing Conference on Tree Mortality Non-bypassable Charge ▪ PG&E contracted a 0.85 MW Municipal BioMAT project ▪ PG&E contracted a 0.3 MW existing small hydro project under the ReMAT Program
July 2017	▪ CPUC adopts D.17-06-026 implementing SB 350 ▪ IOUs, CCAs, and ESPs submitted their RPS Procurement Plans to the CPUC ▪ SCE contracted a 2 MW Municipal BioMAT project ▪ PG&E contracted a 1 MW existing small hydro project under the ReMAT Program
August 2017	▪ IOUs, CCAs, and ESPs submitted their RPS Compliance Reports to Energy Division ▪ CPUC issued D.17-08-021 implementing AB 1979 with revisions to ReMAT ▪ CPUC issued D.17-08-021 implementing AB 1923 expanding eligibility for BioMAT participants ▪ SDG&E contracted a 3 MW project for Municipal BioMAT
September 2017	▪ Biomass facility took price for PG&E Dairy BioMAT contract for a total of 3 MW
October 2017	▪ CPUC issued a Staff Proposal via Ruling to implement AB 1923's provision to interconnect to existing transmission ▪ Biomass facility took price for PG&E Forest BioMAT contract for a total of 5 MW
November 2017	▪ CPUC anticipates issuing a proposed decision on 2017 RPS Procurement Plans
December 2017	▪ SDG&E Expected to Announce Results of RAM ▪ PG&E expected to launch RAM solicitation ▪ CPUC anticipates a final decision on 2017 RPS Procurement Plans

Public Utilities Code 913.4 directs the CPUC to provide information on RPS planning related to cost limitation, implementation, and transmission development. The CPUC utilizes analytical and policy tools to plan for the most cost-effective renewable energy and then implements evaluation processes to measure RPS success. Building off of 2017 RPS efforts, in the coming year, the CPUC will continue to refine and improve policy tools and quantitative methodologies that promote the State's clean energy goals.

Program Planning & Coordination

The CPUC coordinates with its sister State agencies on an ongoing basis to promote and implement consistent statewide RPS policies that benefit all Californians. The CPUC works with the California Energy Commission, California Air Resources Board, California Independent System Operator, and CAL FIRE on such issues and projects as:

- Integrated Resource Planning
- Statewide RPS Compliance and Enforcement
- The Tree Mortality Task Force and its Bioenergy Working Group
- California Renewable Marine Energy Working Group
- Transmission Planning

Statewide RPS Coordination

State agency coordination is at the core of the RPS program, and the CPUC works to align the parallel planning processes of other agencies to improve the program and achieve the State's greenhouse gas emissions reduction goals.

Compliance and Enforcement

The CPUC will continue to coordinate closely with the CEC to ensure a consistent policy approach for RPS compliance and enforcement. CPUC determinations on RPS compliance will rely on the verification report issued by the CEC. The CPUC will utilize the CEC's compliance verification report to inform its future RPS-related compliance decisions.

Tree Mortality and Bioenergy Issues

The CPUC will continue to participate in regular, ongoing forums that address the State's emergency status due to more than a hundred million dead and dying trees in California since 2010. The CPUC is an active participant in the Governor's Tree Mortality Task Force.[25] In addition, RPS staff participates in monthly meetings of the Bioenergy Working Group. The CPUC also engages in other related forums on this topic, such as the Little Hoover Commission.

The issue of tree mortality intersects with the RPS programs of BioMAT and BioRAM. To ensure that these programs address the State's policy goals, CPUC staff will continue to work with other stakeholders to address such issues as program costs, interconnection barriers, and program evaluation.

Marine Renewable Energy

The CPUC is a member of the California Marine Renewable Energy Working Group, which is led by the Ocean Protection Council. The Council seeks to promote regulatory consistency and to improve scientific data that can find common ground for emerging technologies and planning for siting marine renewables. The CPUC's role is to offer insight into the RPS procurement process and the Commission's procedures. The CPUC anticipates working with the Council in the coming year, as the State considers marine renewable energy as a resource.

[25] See http://www.fire.ca.gov/treetaskforce/ for more information.

Ongoing CPUC Planning Efforts for RPS

CPUC staff coordinate internally to ensure that program policy and planning efforts are consistent and cost-effective in providing benefits to ratepayers.

Integrated Resource Planning (IRP)

SB 350 (De León, 2015) requires the CPUC to adopt an IRP process that aims to move away from siloed planning and procurement toward a framework that optimizes potential resource solutions across all applicable retail sellers in order to achieve GHG emissions reductions at the least cost.

On September 19, 2017, CPUC staff released a Proposed Reference System Plan. This Plan identifies a diverse and balanced portfolio of resources capable of ensuring a reliable electricity supply that provides optimal integration of cost-effective renewable energy. By statute, the portfolio must rely upon zero carbon-emitting resources to the maximum extent reasonable and be designed to achieve statewide greenhouse gas emissions limits. The CPUC anticipates issuing a proposed decision by the end of 2017 that will adopt both an IRP process and a Reference System Plan.

Parameters of the Reference System Plan

Staff has proposed that retail sellers should file an IRP by mid-2018 that fits within the parameters set by the Proposed Reference System Plan and ensures that the retail seller will:

- Contribute towards GHG emissions reduction targets for the electricity sector;
- Procure at least 50 percent eligible renewable energy resources by December 31, 2030;
- Enable each IOU to fulfill its obligation to serve its customers at just and reasonable rates;
- Minimize impacts on ratepayers' bills;
- Ensure system and local reliability;
- Strengthen the diversity, sustainability, and resilience of the bulk transmission and distribution systems, and local communities;
- Enhance distributed systems and demand-side energy management; and
- Minimize localized air pollutants and other GHG emissions, with early priority for disadvantaged communities.

CPUC staff propose to analyze and aggregate the retail sellers' IRPs so that the Commission can issue a Preferred System Plan by the end of 2018.

The Reference and Preferred System Plans could inform the RPS procurement targets. Details of how the IRP process will interact with the RPS proceeding are currently being discussed within both proceedings.

Reforms to RPS Least-Cost Best-Fit Methodology

A key part of integrated resource planning is an accurate comparison of resource costs through a Least-Cost Best-Fit (LCBF) methodology. Currently, the utilities implement their own CPUC-approved LCBF methodologies to evaluate bids. This process informs how IOUs select RPS resources that will provide the most value to ratepayers.

Key Issues for LCBF Reform

In order to increase transparency and improve the usefulness of LCBF, the Commission has indicated that several specific issues related to the utilities' LCBF methodologies would be reformed. The specific issues related to the utilities' LCBF methodologies will be addressed in the LCBF reform activity, including:

- Time-of-delivery factors;
- Portfolio optimization;
- Greenhouse gas emissions;
- Disadvantaged communities; and
- Consistency with the RESOLVE modeling tool.[26]

Consequently, the CPUC has developed a set of proposed objectives and a draft work plan for LCBF reform activity that will continue into 2018.

LCBF Reform Objectives

The objectives of LCBF reform recommended by CPUC staff propose to:

1. Ensure compliance with statutory requirements, particularly SB 2 (1X) (Simitian, 2011) and SB 350 (De León, 2015);
2. Improve market efficiency by increasing transparency and consistency of LCBF;
3. Evaluate methodologies used for bid evaluation across utilities and CPUC proceedings; and
4. Lay a foundation for interaction between RPS program and integrated resource planning (IRP).

The CPUC is currently engaging with stakeholders through workshops and formal comments. A CPUC decision on LCBF reform is expected in 2018 in the RPS docket.

[26] RESOLVE is an optimal investment and operational model designed to inform long-term planning questions with regards to renewables integration in systems with high penetration levels of renewable energy. The model is formulated as a linear optimization problem that can solve for the optimal investments in renewable resources, energy storage technologies, new gas plants, and gas plant retrofits subject to an annual constraint on delivered renewable energy that reflects the constraints of the RPS policy, greenhouse gas emissions and maintaining resource adequacy and reliability. For more information see: http://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/UtilitiesIndustries/Energy/EnergyPrograms/ElectPowerProcurementGeneration/LTPP/2017/RESOLVE_CPUC_IRP_Inputs_Assumptions_2017-05-15.pdf

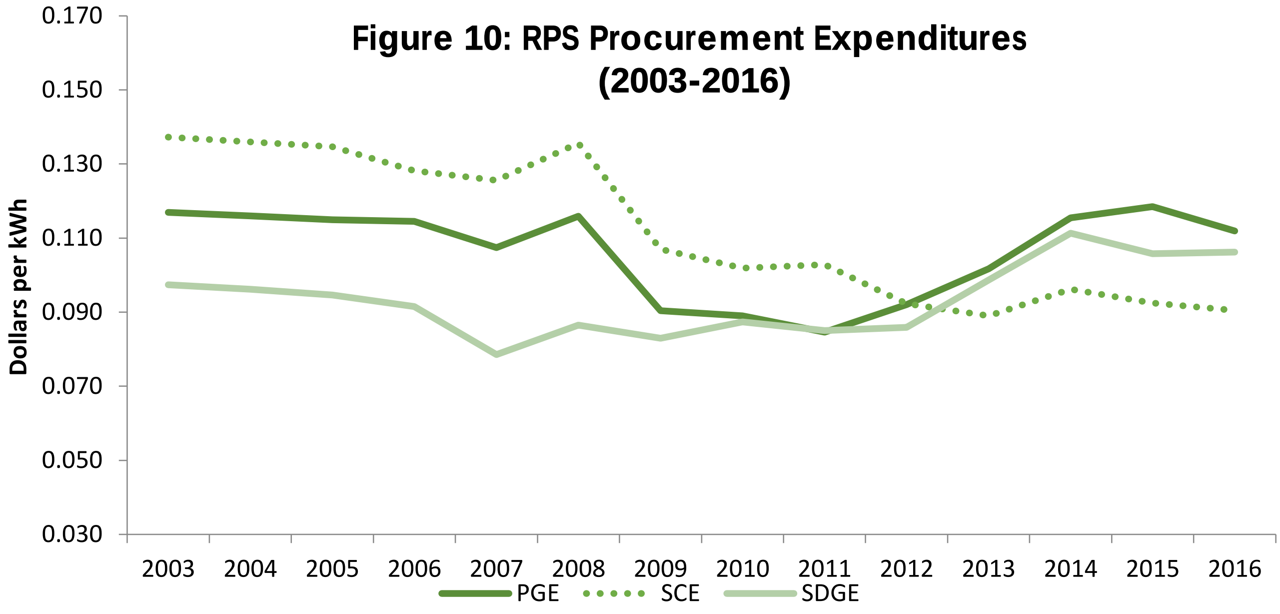
Cost Limitation Projections

To understand the impact that RPS costs will have on ratepayers, the CPUC sets cost-effectiveness policies and collects various price data to understand cost trends. The IOUs use competitive procurement mechanisms and a LCBF evaluation methodology, described above, to ensure procurement of renewable resources that provide the most value in their RPS Procurement Plans. Although the CPUC has not previously established cost limitations for RPS procurement, it is using the IRP as a way to identify the most cost-effective resources to inform future procurement activities.

RPS Procurement Expenditures

Figure 10 illustrates the annual weighted average RPS procurement expenditures for bundled renewable energy in real dollars (prices adjusted for inflation) per kilowatt hour ($/kWh) for each of the large IOUs. The key factor driving the cost differences between the three utilities is the resource mix of RPS resources within an IOU's portfolio and the year the RPS contracts were executed. The RPS contracts that were executed from 2003 to 2008 were more expensive than contracts signed in later years. As the RPS program has expanded, procurement expenditures have expanded in parallel.

In 2018, ratepayers should experience minimal additional rate impacts given that the IOUs do not plan to hold procurement solicitations, and may realize savings from the IOUs' proposed REC sales.



Data Source: IOU RPS Weighted Average RPS Procurement Expenditures, submitted 2016

2017 Renewable Contract Prices

The CPUC tracks the cost of renewables to understand the impact on ratepayers. California's investment in renewables has increased over time and, therefore, the price of solar PV and wind contracts have been decreasing significantly. This section focuses on solar and wind trends given that they are the primary resources used to meet RPS requirements in the State.[27]

As demonstrated in Chapter 2, California's RPS requirements have contributed to increased investment in renewable resources. Relative to other renewable technologies, the utility-scale solar and wind market has expanded rapidly and the prices have decreased significantly in the last decade. The consistent decrease in the average prices of solar PV projects are reflected in the sharp decrease in IOU contract prices observed from 2008 to 2016. Similarly, the decrease in the cost of developing wind projects can be observed through the decline in the average prices of wind contracts from 2007 to 2015.

Solar PV: IOU Contract Prices Decreased 77% from 2010 to 2016

Table 14 shows the percent change in the prices of solar contracts from 2008, 2010, and 2016. The prices of solar PV declined significantly from 2008 to 2016. The prices of utility-scale solar contracts have decreased roughly 77 percent from 2010 to 2016, from an average of $127.55/MWh to an average of $29.17/MWh.

Table 14: Average Contract Prices for Utility-Scale Solar PV Projects (> 20 MW)

Year	Average Price ($/MWh)	% Change
2008	135.90	
2010	127.55	-6%
2016	29.17	-77%

Data Source: RPS Contract Database Submissions, October 2017

[27] See http://www.caiso.com/informed/Pages/CleanGrid/default.aspx for more information on California's renewables breakdown.

Wind: IOU Contract Prices Decreased 47% from 2010 to 2015

Table 15 shows the percent change in the prices of wind contracts from 2007, 2010, and 2015. The data show that the average prices of utility-scale wind contracts have decreased approximately 47 percent in the last decade from an average of $96.72/MWh in 2010 to $50.99/MWh in 2015.[28]

Table 15: Average Contract Prices for Utility-Scale Wind Projects (> 20 MW)

Year	Average Price ($/MWh)	% Change
2007	97.11	
2010	96.72	-0.4%
2015	50.99	-47%

Data Source: RPS Contract Database Submissions, October 2017

Transmission Development Supporting RPS Implementation

The CPUC works with other State agencies and organizations in the planning of transmission, necessary to support the delivery of renewable energy to California homes and businesses. Transmission planning can take several years from the initial Transmission Planning Process with the Energy Commission and the CAISO to the CPUC's role in required environmental review.

The CPUC is responsible for ensuring that transmission-related projects comply with the California Environmental Quality Act (CEQA). CPUC staff perform detailed CEQA analysis to identify and mitigate environmental impacts from large-scale utility projects and to identify alternatives to the projects.

Suncrest Dynamic Reactive Power Support Project

The CPUC is in the process of evaluating NextEra Energy Transmission West's (NEET) application to construct an upgrade to Suncrest Substation. The proposed project is purported to support increased renewable generation in Southern California. CAISO selected NEET West through a competitive solicitation after finding that the *Suncrest Dynamic Reactive Power Support Project* met stringent bid requirements to address forecasted increases in renewable generating capacity in the Imperial Valley, due to the retirement of the San Onofre Nuclear Generating Station (SONGS).

As part of its 2013-2014 transmission planning process, CAISO determined that the proposed project was needed to address voltage stability issues on the grid. Voltage stability refers to the ability of power systems to maintain a steady voltage, which is necessary to ensure that the system provides continuous, reliable power to all users.

[28] This does not reflect any further reductions in wind contract prices in 2016 or 2017 because the IOUs did not execute wind contracts in those years.

The CPUC's Draft Environmental Impact Report was circulated in November 2016. Formal Proceeding testimony for the project was held in July 2017, with project hearings held in August. A draft of the Final Environmental Impact Report is due before the end of 2017, with a final CPUC Suncrest decision on the proposed project expected in 2018.

California's climate policies and robust RPS program are impacting the demand for an educated and qualified "clean tech" workforce. This chapter describes RPS workforce development activities of the large IOUs and SMJUs, consistent with Public Utilities Code 913.4(f). This statute requires the CPUC to report on the efforts of California's electrical corporations related to workforce development, training, and diversity.

Overview of RPS Workforce

Chapter 5 provides details on efforts of the large IOUs and SMJUs related to:

- Current RPS workforce;
- Diversity of current staff;
- Strategies used to recruit a diverse staff and develop RPS and other clean energy staff of the future; and
- Training IOUs provide for their current workforce.

The CPUC gathered information on the above topics directly from each of the IOUs.

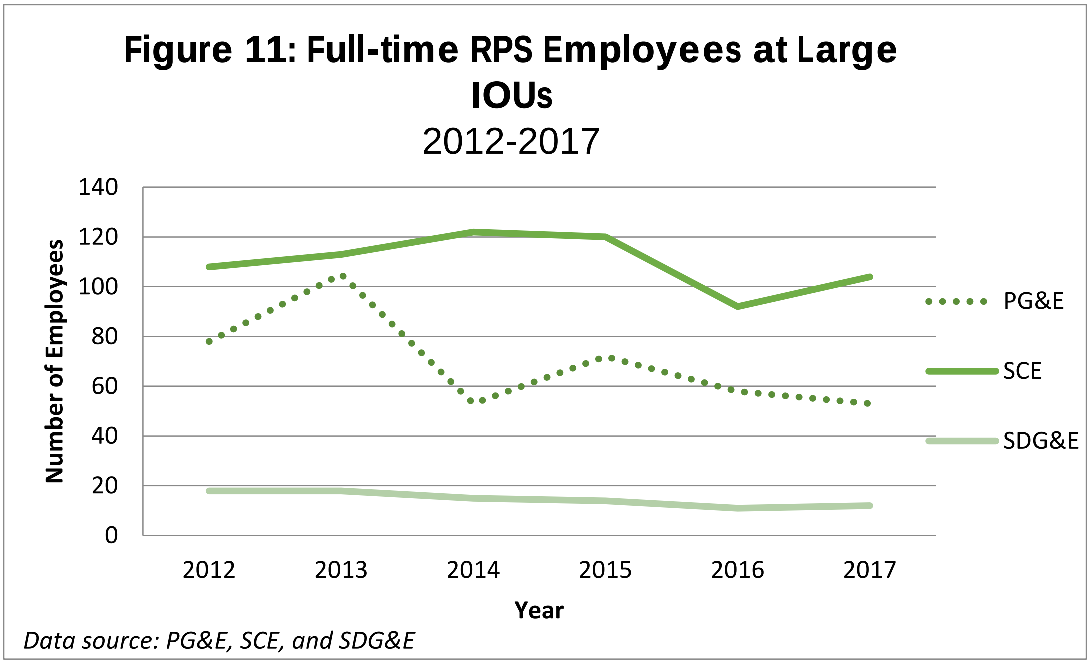
This chapter first describes the workforce development of the large IOUs and is followed by information on the SMJUs.

Large IOU Workforce Development

The large IOUs report having a significant focus on offering equal employment opportunities with respect to the recruitment, hiring, and professional development practices associated with the implementation of the RPS program.

Current IOU RPS Workforce

Figure 11 below provides an overview of the number of full-time PG&E, SCE, and SDG&E employees who have worked on RPS-related issues from 2012-2017. This graph illustrates how the IOUs' RPS staffs have changed over the past five years.[29]

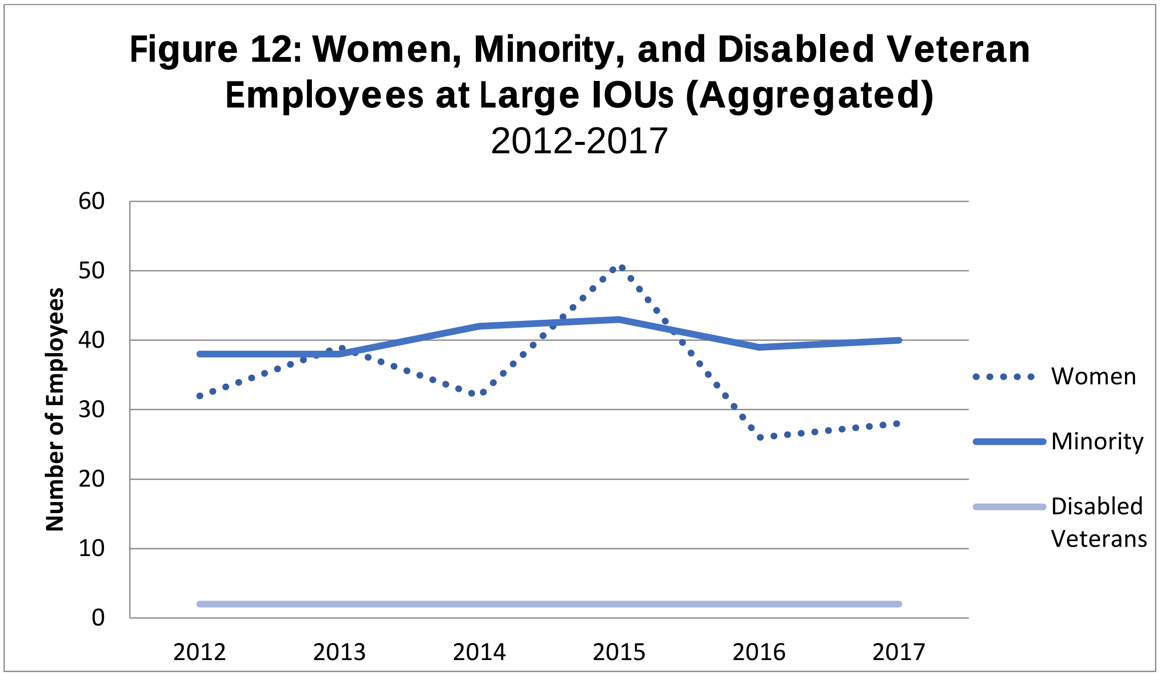


IOU Current RPS Workforce Diversity

The large IOUs have reported having company-wide diversity goals to build a workforce that reflects the diversity of the State of California. Common diversity efforts across the IOUs include providing equal employment opportunity in all aspects of their employment practices and hiring more women, minority, and disabled veterans for the purposes of implementing the RPS program.[30]

[29] This time series data is current as of August 2017 and includes employment data from January 2012 through July 2017.

[30] PG&E, SCE, and SDG&E do not track if their employees identify as Lesbian, Gay, Bisexual, and Transgender (LGBT). While the three large IOUs do not collect data on LGBT employees, they do have supplier diversity requirements as set out in General Order 156 and are required to submit an annual Supplier Diversity Report.



In 2017, all three large IOUs reported working with organizations focused on professional development for women, minority, and disabled veterans. They were also compliant with General Order 156[31] requirements on supplier diversity. Figure 12 illustrates aggregated data on the number of Women, Minorities, and Disabled Veterans who are full time employees at the three large IOUs who work on the RPS program.

Pacific Gas and Electric Company (PG&E):

Table 16 shows the number of PG&E's RPS employees that are women, minority, and disabled veterans compared with total RPS staff. In 2016, 74% of PG&E's RPS staff was comprised of women, minorities, or disabled veterans.

Table 16: Number of Women, Minority, and Disabled Veteran RPS Employees from 2012-2017 (PG&E)

PG&E	RPS Employees (Full Time)					
	2012	2013	2014	2015	2016	2017
Women	32	39	20	36	13	14
Minority	38	37	35	32	28	29
Disabled Veterans	2	2	2	2	2	2
Total RPS Staff	78	105	53	72	58	53

[31] General Order 156 refers to the rules governing the development of programs to increase participation of women, minority, disabled veterans and LGBT business enterprises in procurement contracts from IOUs as required by Public Utilities Code Sections 8281-8286.

Southern California Edison (SCE):

SCE reported that 73% of the company's RPS employees are either women or minorities. Table 17 below shows the number of SCE's RPS employees that are women, minority, or disabled veterans. In 2016, 75% of SCE's total RPS staff was comprised of women, minorities, or disabled veterans.

Table 17: Number of Women, Minority, and Disabled Veteran RPS Employees from 2012-2017 (SCE)

SCE	RPS Employees (Full Time)					
	2012	2013	2014	2015	2016	2017
WMDV[32]	71	73	81	84	69	76
Women	No Data				29	31
Minority	No Data				40	45
Total RPS Staff	108	113	122	120	92	104

San Diego Gas & Electric Company (SDG&E):

Table 18 illustrates the number of SDG&E's RPS employees that are women, minority, or disabled veterans.

Table 18: Number of Women, Minority, and Disabled Veteran RPS Employees from 2012-2017 (SDG&E)

SDG&E	RPS Employees (Full Time)					
	2012	2013	2014	2015	2016	2017
Women	No Data	No Data	12	15	13	14
Minority	No Data	No Data	7	11	11	11
Disabled Veterans	No Data					
Total RPS Staff [33]	18	18	15	14	11	12

[32] Women Minority and Disabled Veterans (WMDV) were tracked as one data point by SCE until 2016. Disabled veterans are not being tracked as separate data points.

[33] The value displayed for the total number of RPS staff is based on the percentage of time employees actually spend working on RPS issues (a range of 0 to 100%), while the WMDV information is calculated based on whether or not the employee is a woman, minority, or disabled veteran.

SDG&E reported having one RPS contract in 2017 with a minority owned business enterprise. SDG&E uses a qualitative component when evaluating contracts to determine which projects are the best fits for SDG&E's portfolio. This qualitative component includes the Diverse Business Enterprise (DBE) status of a project and SDG&E has reported strongly encouraging DBEs, including women-owned, minority-owned, disabled veteran owned or LGBT owned business enterprises to participate in its renewable power related Request for Offer solicitations.

Recruiting Strategies

Recruiting efforts at each of the IOUs tend to utilize both broad outreach, as well as strategies targeted to a diverse community. In addition, the utilities also offer programs that can act as training and recruitment of future employees, including long-term efforts within California's school systems.

PG&E

General Outreach:

As part of its broader recruiting efforts, PG&E frequently utilizes online job boards and reaches out to prospective candidates through websites such as LinkedIn, Getting Hired, and Direct Employers.

Diverse Employee Recruitment:

PG&E works with groups such as the Society of Women Engineers, National Society of Black engineers, Society of Hispanic Professional Engineers, and specific university programs to encourage a diverse candidate pool. Open positions at PG&E are frequently posted on electronic job boards targeted to diverse recruitment, such as GIJobs.com, Out and Equal Workplace Advocates, and Hero 2 Hired. However, PG&E has not reported a formal company policy outlining the strategies for increasing the amount of women, minority, disabled veterans, and LGBT employees working on the RPS program.

University Outreach:

PG&E has a "University Programs" team primarily focused on recruitment activities on California college campuses such as UC San Diego, UC Davis, UC Merced, Cal Poly San Luis Obispo, Sacramento State, and Chico State. The University Programs team targets recent college graduates who have studied engineering, finance, business, information technology, and environmental science.

Special Programs:

PG&E administers a separate recruitment and training program called PowerPathway that consists of a partnership with community colleges throughout PG&E's service territory. The PowerPathway program has two separate arms – the Affinity Program and PG&E's Signature Program.

- **Affinity Program:** PG&E provides input on certificate and degree curriculums, introduces college staff to PG&E subject matter experts, and arranges for PG&E sponsored guest speakers to give in-class presentations.
- **Signature Program:** Entails assisting community college professors through providing input on curriculum and technical training coursework, as well as providing up to three years of career coaching for program graduates.

From 2012 through June 2017, the PowerPathway Signature Program has mentored 575 program graduates. Of those graduates, 46% of the graduates were placed into full time positions at PG&E and 34% of graduates went on to pursue industry-related careers. PG&E is developing a new PowerPathway Skilled Trades internship program that aims to recruit, train, and produce new qualified professionals for the future utility workforce.

K-12 Outreach & Education:

In addition to working with university and community colleges, PG&E has a K-12 program to expose a younger generation to careers in sustainability.

SCE

General Outreach:

As a part of their targeted recruitment efforts for clean energy professionals, SCE recruits through online job sites such as LinkedIn, Direct Employers, and Glassdoor. With regards to college recruitment, SCE has reported robust recruitment efforts and outreach strategies targeted at students pursuing undergraduate degrees in engineering, accounting, finance, information technology and cyber security.

SCE leverages social media, including hosting a YouTube channel where they post videos for the public on a variety of topics including the electricity grid of the 21st century, updates on renewable energy project developments, and grid reliability.

University Outreach:

SCE actively recruits and employs interns from four California State Universities, five University of California schools, and the University of Southern California. SCE has also created a rotational development program for MBA students and partners with the East Los Angeles Skills Center to help prepare interested students for energy careers. In 2016, SCE employed 59 interns from California Polytechnic University Pomona, where 15 of those interns went on to become full time employees after graduation.

SDG&E

General Outreach:

SDG&E's recruitment and workforce development efforts center on targeting students primarily from universities in California and Nevada who are studying accounting, finance, engineering, and information technology. SDG&E reports that it uses LinkedIn to advertise job vacancies and participation on group pages to recruit qualified candidates for open positions.

Diverse Employee Recruitment:

SDG&E places a large emphasis on college recruiting and recruitment from diverse professional development organizations including the Society of Women Engineers, National Society of Black Engineers, and the Society of Mexican-American Engineers. As a part of its workforce development and recruitment efforts, SDG&E partners with universities that have a high minority student population such as Howard University, San Diego State University, California Polytechnic University Pomona, and the University of Nevada/Las Vegas. On the recruitment marketing and social media front, SDG&E leverages social media websites focused on professionals in energy with diverse backgrounds such as Women Working in Utilities, American Association of Blacks in Energy, and Hispanics in Energy.

University Outreach:

In 2017, SDG&E began a new paid internship program with UC San Diego and Southwestern College designed to prepare students for clean energy careers with career pathways such as Solar Design and Energy Storage.

K-12 Outreach & Education:

SDG&E offers a workforce education and training program for K-12 students interested in green energy, science, technology, engineering and mathematics (STEM) careers. From September 2016 through August 2017, approximately 10,000 K-12 students have completed the program.

SMJU Workforce Development

Given the smaller size of their RPS staffs, the three SMJUs (Bear Valley Electric Service, Liberty Utilities, PacifiCorp) have significantly fewer resources dedicated to RPS workforce development. For example, on average, the SMJUs employ between one to three full-time RPS employees.

Bear Valley Electric Service (BVES)

BVES has not engaged in college recruitment efforts or offered scholarships to students within their service territory. Bear Valley Electric Service does not conduct internal training courses but RPS employees are encouraged to attend training and workshops elsewhere in the State.

Liberty Utilities

Out of the three SMJUs, Liberty Utilities is the only utility to engage in recruitment efforts with local high schools and universities. During the summer of 2017, Liberty attended a career fair at the University of Nevada, Reno and recruited two student engineers for positions after graduation. Liberty also posts job opportunities on career fair web portals at local universities. Liberty Utilities offers scholarships to graduating high school students within the service territory and offers one community college scholarship. With regards to RPS-focused training, Liberty Utilities conducted one training course on the RPS program and greenhouse gas emission reduction strategies for five employees from 2016-2017.

Liberty stated that it is an equal opportunity employer and is committed to ensuring an equal and diverse workforce to implement the RPS program. In 2017, Liberty reported hiring two additional employees to implement the RPS program, both of which are minority recruits.

PacifiCorp

PacifiCorp has not engaged in college recruitment efforts or offered scholarships to students within their service territory. PacifiCorp employs one person to work on RPS related issues throughout all states served by PacifiCorp and does not conduct internal training for that employee.

Given that PacifiCorp employs one employee who oversees the RPS program in all states served by PacifiCorp, no specific diversity statistics were provided.

Public Utilities Code 913.4 requires the CPUC to identify barriers to achieving the RPS, and to propose recommendations to address those barriers. Chapter 6 examines at a high level RPS program challenges and describes actions the CPUC is taking to address these issues, as well as offers recommendations for future actions. The challenges addressed in this chapter include the areas of RPS procurement, ratepayer impacts, and the individual RPS programs of ReMAT and BioMAT.

Challenge 1: <u>Uncertainty in IOU Load Forecasts</u>

Issue: It is difficult to forecast future IOU load, given increasing departing load to CCAs. Current CPUC estimates suggest that over 1 million IOU ratepayers will be served by CCAs for their generation needs by the end of 2017. Forecasting scenarios suggest that some IOUs could lose 60 to 90 percent of their current demand in the next 8 to 10 years. This number is expected to grow quickly. As additional CCAs are formed, the CPUC will oversee a significantly smaller percentage of renewable procurement in the State, as the CPUC has limited jurisdiction over the procurement activities of CCA or ESP providers. If the IOUs lose such large portions of their customer demand, the result will be that the CPUC will not have the authority to monitor most renewable energy procurement activities in as much detail, as it has traditionally done for RPS. This may cause challenges in the IRP process due to the CPUC's lack of market visibility with regards to CCA and ESP procurement activities.

Recommendation: The CPUC should continue to closely monitor procurement activities of all the retail sellers to the extent possible. The CPUC forecast models for the IRP process will be used to develop optimum portfolios to meet California's GHG goals. This process is continuing and will ultimately lead to procurement authorizations for the IOUs and IRP plans for IOUs, CCAs, and ESPs. The IRP proceeding and the RPS planning process should work together to achieve California's GHG and renewable goals.

Challenge 2: Increased Amounts of Renewables have Resulted in Increased Incidents of Curtailment

Issue: Curtailment of renewable generation has increased in recent years as more solar has been added to the grid. The initial finding of the CPUC's IRP modeling is that curtailment is a cost-effective strategy for integrating more renewable capacity, rather than investing in other integration options such as transmission upgrades or energy storage. While curtailment does not appear to be a barrier to achieving current RPS requirements, there is a need to fully understand the causes of curtailment and ways to reduce its frequency.

In most other parts of the country, wholesale markets continue to report negligible levels of curtailment. The addition of significant wind capacity in Texas and the Midwest has caused increased congestion and curtailment in those regions. To address the issue, the Electric Reliability Council of Texas (ERCOT) has expanded its transmission grid and adopted market rules to facilitate economic curtailment, and the Midcontinent Independent System Operator (MISO) has promoted economic curtailment.

Recommendation: The State should rely upon the CPUC's IRP process to balance the increased procurement of renewables with the risk of curtailment. Initial modeling results in the IRP proceeding indicate that buying additional solar and economically curtailing renewable resources in the limited hours of the year when they are not needed is a cost-effective strategy to integrating more renewables into the grid and displacing natural gas generation. Further, recent data suggests that curtailment is not a significant risk. While the CAISO has seen the number of pricing intervals with negative prices increase over the last several years, the clearing prices are becoming less negative. In other words, the frequency of negative pricing events has increased, but the magnitude of each curtailment event has lessened. This indicates that the CAISO has generally been able to balance supply and demand using economic signals.

Challenge 3: Stranded Costs Resulting from Increased Departing Load Could Fall to IOU Customers

Issue: As described above, there is significant departing load from the increasing formation of CCAs. As a result, there is a significantly smaller ratebase of customers over which to allocate energy costs. Policies established now, but implemented after the load has departed could result in stranded costs and rate shock for remaining bundled IOU customers. Parties are challenging the current mechanisms in place to prevent IOU ratepayers from paying for stranded assets. This is illustrated in current proceedings such as BioRAM to address Tree Mortality, and in the more global proceeding for the Power Charge Indifference Adjustment (PCIA).

Recommendation: The CPUC has open proceedings to develop workable solutions to these challenges. Any new procurement strategies should consider the impact of policies on ratepayers in the context of weighing all costs and benefits to ratepayers. In addition, the IRP process proposes to take a system wide view at the combined planning and procurement of IOUs, CCAs, and ESP providers, which should provide a roadmap to not only reach GHG goals, but also to achieve cost-effective procurement recommendations.

Challenge 4: The ReMAT Program Has Experienced Significant Project Terminations and Uneven Market Interest

Issue: As explained in the report, the IOUs do not need to execute any additional ReMAT contracts to achieve the RPS. It is worth noting that the ReMAT program has resulted in large percentages of terminated capacity since the program commenced in 2013. The proportion of capacity terminated by the IOUs has been:

- PG&E = 48%
- SCE = 30%
- SDG&E = 56%

These termination percentages are higher than the termination levels seen for large-scale (>20 MW) projects. It is not clear why there are such varying results and whether such terminations are related to developer experience, project viability, interconnection, permitting challenges, and/or lack of financing for small projects.

Additionally, there has been uneven interest among the three product categories:

- As-Available Peaking;
- As-Available Non-Peaking; and
- Baseload.

For the As-Available Peaking category, 12.1 MWs are currently under contract, whereas there is only 1 MW for the Baseload category. As a result of the uneven interest, the allocated As-Available Peaking MWs may be fully contracted while significant capacity remains in the other categories.

A challenge of the ReMAT Baseload category, or reason for lack of market interest, may be the overlap with the BioMAT program. Some of the projects that could be eligible for the ReMAT Baseload category could also be eligible for BioMAT, which currently has a higher offered price.

While the program initially saw regular adjustments in price and execution of contracts, activity has slowed down. For example, PG&E's offered price for As-Available Peaking category has not changed over the last 24 months. SDG&E has suspended its ReMAT program. SCE has recently reached the procurement level in As Available Peaking where, it could soon suspend its entire ReMAT program by the end of 2019.

Recommendation: The Commission plans to review these program challenges, as well as recent market observations, within the scope of the RPS proceeding in order to obtain stakeholder input. In reviewing the issues and stakeholder input, the CPUC should consider possible program modifications that could address these concerns.

Challenge 5: The BioMAT Program Appears to Have Limited Market Interest

Issue: As previously noted, the IOUs do not need to execute any additional BioMAT contracts to achieve the RPS. The original objective of the BioMAT program was to create a simple procurement mechanism for new bioenergy developer entrants of up to 3 MWs. BioMAT is comprised of three categories of bioenergy (Biogas, Dairy/Other Agriculture, and Forest Biomass) for which SB 1122 (2012, Rubio) allocated a total of 250 MWs. In the three categories, there has been little activity:

- **Biogas:** There was market activity at the initial price of $127/MWh, but the category price has since remained stagnant, with a total of 7.4 MWs of executed contracts.
- **Dairy and Other Agriculture:** There was no initial market activity, but the price of $187.72/MWh was taken in the period from August 1, 2017 program period, for a total of 3 MWs.
- **Forest:** There was no initial market activity, but the price of $199.72/MWh was taken in the period from October 1, 2017 period for a total of 5 MWs.

Only 15.4 MW have been subscribed out of the total 250 MW allocated since the program's initial offering in February 2016. While each category has its respective barriers, key challenges appear to be related to the high costs associated with equipment and interconnection.

Recommendation: In its 2014 decision implementing the BioMAT program, the Commission established ratepayer protections to investigate the BioMAT program if the program price were to reach $197/MWh for more than two program periods. The Forest category reached this threshold on November 1, 2017. The Director of Energy Division now also has the discretion to suspend the awarding of BioMAT contracts. Accordingly, the CPUC should seek stakeholder input to identify potential ways to simplify and improve the program, address barriers to increased participation, and evaluate potential program cost limitations.

APPENDIX A

Glossary of Acronyms and Terms

BioMAT: The Bioenergy Market Adjusting Tariff is a feed-in tariff program for bioenergy renewable generators less than 3 MW in size.

BioRAM: The Bioenergy Renewable Auction Mechanism (BioRAM) program implements the Governor's October 2015 Emergency Order on Tree Mortality, as well as SB 859, and mandates utilities to procure bioenergy from forest fuel from High Hazard Zones (HHZ) to mitigate the threat of wildfires.

CBA – California Balancing Authority: A balancing authority is charged with maintaining the safe and reliable transportation of electricity on the power grid and ensures transparent access to the transmission network and market transactions.

CCA - Community Choice Aggregator: CCAs are local government agencies that purchase and may develop power on behalf of residents, businesses, and municipal facilities within a local or sub-regional area. As of November 1, 2017, there are 9 operational CCAs in California.

Electrical Corporation: An electrical corporation includes every corporation or person owning, controlling, operating, or managing any electric plant for compensation within California, except where electricity is generated on or distributed by the producer through private property solely for its own use (not for transmission to others).

ESP - Electric Service Provider: An ESP is an entity that offers electrical service to customers within the service territory of an electrical corporation and includes the unregulated affiliates and subsidiaries of an electrical corporation.

GTSR - Green Tariff Shared Renewables: The GTSR Program is intended to expand access to all eligible renewable energy resources to ratepayers who are unable to access the benefits of onsite generation and create a mechanism where customers can meet their electricity needs with renewables. The GTSR program is designed to allow PG&E, SCE, and SDG&E customers to receive 50% - 100% of their electricity demand from solar generation.

IRP - Integrated Resource Plan: A planning mechanism to consider all of the CPUC's electric procurement policies and programs to ensure California has a safe, reliable, and cost-effective electricity supply. It will implement an integrated resource planning process that will ensure that retail sellers meet targets that allow the electricity sector to contribute to California's economy-wide greenhouse gas emissions reductions goals.

IOU - Investor-Owned Utility: IOUs are privately owned electricity and natural gas providers and are regulated by the California Public Utilities Commission (CPUC). Pacific Gas and Electric, San Diego Gas and Electric, and Southern California Edison comprise approximately three quarters of the retail electricity supply in California.[34]

LCBF - Least-Cost Best-Fit: A process that provides criteria for the rank ordering and selection of least-cost and best-fit eligible renewable energy resources to comply with California's Renewables Portfolio Standard program obligations on a total cost and best fit basis.[35]

LSE - Load Serving Entity: All entities that serve electricity to customers including IOUs, CCAs, and ESPs.

PPA – Power Purchase Agreement: The contractual agreement under which the financial and technical aspects of renewable energy generation projects are agreed upon between power sellers and retail sellers.

RAM - Renewable Auction Mechanism: The RAM program is a procurement program the IOUs may use to procure RPS generation and to satisfy authorized procurement needs or legislative mandates. RAM streamlines the procurement process for developers, utilities, and regulators by 1) allowing project bidders to set their own price, 2) providing a simple standard contract for each utility, and 3) allowing all contracts to be submitted to the CPUC through an expedited regulatory review process.

REC - Renewable Energy Credit: RECs play an important role in driving the deployment of renewable energy in California and achieving the goals of Renewables Portfolio Standard (RPS). A REC confers to its holder a claim on the renewable attributes of one unit of energy (MWh) generated from a renewable resource. A REC consists of the renewable and environmental attributes associated with the production of electricity from a renewable source. RECs are "created" by a renewable generator simultaneous to the production of electricity and can subsequently be sold separately from the underlying energy.

ReMAT – Renewable Market Adjusting Tariff: ReMAT is a feed-in tariff program for small renewable generators up to 3 MW in size.

RPS - Renewables Portfolio Standard: Established in 2002 under Senate Bill 1078, accelerated in 2006 under Senate Bill 107, expanded in 2011 under Senate Bill 2, and enhanced further in 2015 with Senate Bill 350 California's RPS is one of the most ambitious renewable energy standards in the country. The RPS program requires investor-owned utilities (IOUs), electric service providers, and community choice aggregators to increase procurement from eligible energy resources to 50% of total procurement by 2030.

Retail Sellers: All entities that sell electricity to customers, including IOUs, CCAs and ESPs. A Publicly Owned Utility does not meet the definition of a retail seller and is regulated by the CEC.

[34] For information on the differences between Publicly-Owned Utilities and Investor-Owned Utilities, please visit the California Energy Commission's website: http://www.energy.ca.gov/pou_reporting/background/difference_pou_iou.html

[35] For more information on the LCBF methodology see Public Utilities Code 399.13(A).

APPENDIX B

Public Utilities Code Section 913.4

In order to evaluate the progress of the state's electrical corporations in complying with the California Renewables Portfolio Standard Program (Article 16 (commencing with Section 399.11) of Chapter 2.3), the commission shall report to the Legislature no later than November 1 of each year on all of the following:

(a) The progress and status of procurement activities by each retail seller pursuant to the California Renewables Portfolio Standard Program.

(b) For each electrical corporation, an implementation schedule to achieve the renewables portfolio standard procurement requirements, including all substantive actions that have been taken or will be taken to achieve the program procurement requirements.

(c) The projected ability of each electrical corporation to meet the renewables portfolio standard procurement requirements under the cost limitations in subdivisions (c) and (d) of Section 399.15 and any recommendations for revisions of those cost limitations.

(d) Any renewable energy procurement plan approved by the commission pursuant to Section 399.13, schedule, and status report for all substantive procurement, transmission development, and other activities that the commission has approved to be undertaken by an electrical corporation to achieve the procurement requirements of the renewables portfolio standard.

(e) Any barriers to, and policy recommendations for, achieving the renewables portfolio standard pursuant to the California Renewables Portfolio Standard Program.

(f) The efforts each electrical corporation is taking to recruit and train employees to ensure an adequately trained and available workforce, including the number of new employees hired by the electrical corporation for purposes of implementing the requirements of Article 16 (commencing with Section 399.11) of Chapter 2.3, the goals adopted by the electrical corporation for increasing women, minority, and disabled veterans trained or hired for purposes of implementing the requirements of Article 16 (commencing with Section 399.11) of Chapter 2.3, and, to the extent information is available, the number of new employees hired and the number of women, minority, and disabled veterans trained or hired by persons or corporations owning or operating eligible renewable energy resources under contract with an electrical corporation. This subdivision does not provide the commission with authority to engage in, regulate, or expand its authority to include, workforce recruitment or training.

EXHIBIT
3

Two methods for estimating limits to large-scale wind power generation

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Edited* by Christopher J. R. Garrett, University of Victoria, Victoria, BC, Canada, and approved June 25, 2015 (received for review May 6, 2014)

Wind turbines remove kinetic energy from the atmospheric flow, which reduces wind speeds and limits generation rates of large wind farms. These interactions can be approximated using a vertical kinetic energy (VKE) flux method, which predicts that the maximum power generation potential is 26% of the instantaneous downward transport of kinetic energy using the preturbine climatology. We compare the energy flux method to the Weather Research and Forecasting (WRF) regional atmospheric model equipped with a wind turbine parameterization over a 10^5 km^2 region in the central United States. The WRF simulations yield a maximum generation of 1.1 $W_e{\cdot}m^{-2}$, whereas the VKE method predicts the time series while underestimating the maximum generation rate by about 50%. Because VKE derives the generation limit from the preturbine climatology, potential changes in the vertical kinetic energy flux from the free atmosphere are not considered. Such changes are important at night when WRF estimates are about twice the VKE value because wind turbines interact with the decoupled nocturnal low-level jet in this region. Daytime estimates agree better to 20% because the wind turbines induce comparatively small changes to the downward kinetic energy flux. This combination of downward transport limits and wind speed reductions explains why large-scale wind power generation in windy regions is limited to about 1 $W_e{\cdot}m^{-2}$, with VKE capturing this combination in a comparatively simple way.

generation limits | turbine–atmosphere interactions | wind resource | kinetic energy flux | extraction limits

Wind power has progressed from being a minor source of electricity to a technology that accounted for 3.3% of electricity generation in the United States and 2.9% globally in 2011 (1, 2). Combined with an increase in quantity, the average US wind turbine also changed from 2001 to 2012; hub height increased by 40%, rotor-swept area increased by 180%, and rated capacity increased by 100% (2). Likely a combination of both the above-noted technological innovations and improved siting, the per-turbine capacity factor, the ratio of the electricity generation rate (MW_e) to the rated capacity (MW_i), increased globally from 17% in 2001 to 29% in 2012 (1, 2), making a recently deployed wind farm likely to generate about 70% more electricity from the same installed capacity.

Combining climate datasets with these observed trends of greater-rated capacities and capacity factors, several academic and government research studies estimate large-scale wind power electricity generation rates of up to 7 $W_e{\cdot}m^{-2}$ (3–7). However, a growing body of research suggests that as larger wind farms cover more of the Earth's surface, the limits of atmospheric kinetic energy generation, downward transport, and extraction by wind turbines limits large-scale electricity generation rates in windy regions to about 1.0 $W_e{\cdot}m^{-2}$ (8–14). Ideally, these inherent atmospheric limitations to generating electricity with wind power could be considered without scenario- and technology-specific complex modeling approaches, be easily applied to "preturbine" climatologies, and yield spatially and temporally variable generation rates comparable to the energetically consistent atmospheric modeling methods.

Here, we describe such a simple method that focuses on the vertical downward transport of kinetic energy from higher regions of the atmosphere to the surface. In the absence of wind farms, the downward flux of kinetic energy is dissipated by turbulence near the surface, which shapes near-surface wind speeds. When wind farms use some of this kinetic energy, the vertical balance between the downward kinetic energy flux and turbulent dissipation is altered and results in lower hub-height wind speeds. The more kinetic energy wind farms use, the greater the shift in the balance and the reduction of wind speeds should be. This trade-off between greater utilization and lower wind speeds results in a maximum in wind power generation from the vertical flux of kinetic energy (10). This maximum yields a potential for wind power generation of a region that is independent of the technological specifications of the turbines. Because this method is based on the vertical downward transport of kinetic energy, we refer to it as the vertical kinetic energy (VKE) method. Note that this reasoning assumes that the downward flux of kinetic energy remains unchanged, which was shown to be a reasonable assumption compared with climate model simulations at the continental scale (11), but which may not hold at the regional scale.

Here we evaluate the applicability of this method by using high-resolution simulations with the Weather Research and Forecasting (WRF) regional atmospheric model with a wind turbine parameterization. We use the region of central Kansas during the typical climatological period of June–September 2001, noting that this

Significance

Wind turbines generate electricity by removing kinetic energy from the atmosphere. We show that the limited replenishment of kinetic energy from aloft limits wind power generation rates at scales sufficiently large that horizontal fluxes of kinetic energy can be ignored. We evaluate these factors with regional atmospheric model simulations and find that generation limits can be estimated from the "preturbine" climatology by comparatively simple means, working best when the atmosphere between the surface and hub height is naturally well-mixed during the day. Our results show that the reduction of wind speeds and limited downward fluxes determine the limits in large-scale wind power generation to less than 1 $W{\cdot}m^{-2}$.

Author contributions: L.M.M., N.A.B., and A.K. designed research; L.M.M., N.A.B., D.B.M., F.G., A.J.M., R.V., D.W.K., and A.K. performed research; L.M.M., N.A.B., D.B.M., and A.K. analyzed data; and L.M.M., N.A.B., D.B.M., A.J.M., R.V., D.W.K., and A.K. wrote the paper.

The authors declare no conflict of interest.

*This Direct Submission article had a prearranged editor.

Freely available online through the PNAS open access option.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1408251112/-/DCSupplemental.

period is before large-scale wind power deployment within this region. We then use the WRF simulation of this time period without wind farm effects to obtain the downward transport of kinetic energy into the region. This flux is used by the VKE method to predict the limit for wind power generation of the region. This limit as well as its temporal variations are then compared with a set of sensitivity simulations of the WRF model using different installed capacities of 0.3–100 $MW_i{\cdot}km^{-2}$ to derive the maximum wind power generation rate (the WRF method). These regional results will then be used within a broader interpretation on the role of horizontal and vertical kinetic energy fluxes to wind farms of differing installed capacities and spatial scales. We close with a brief conclusion on the implications of these two approaches for estimating large-scale wind power generation.

Methods

To evaluate the limits to wind power generation, we use a reference climatology of Central Kansas for the time period of May 15 to September 30, 2001 using the WRF-ARW v3.3.1 regional weather forecasting model (15, 16), forced with North American Regional Reanalysis data (17). This particular time period is climatologically representative for this region: a near-neutral El Niño southern oscillation phase, a climatologically standard position and strength of the Great Plains low-level jet, and an average summer soil moisture content (18). The simulation uses a single domain with a horizontal grid spacing of 12 km and 31 vertical levels, and the first 15 d of the simulation are excluded from the analysis to avoid spin-up effects. This WRF simulation represents our control simulation, which is used as input to the VKE method and as a reference for various WRF simulations with different densities of installed wind turbines to obtain the limit for wind power generation using the WRF method.

WRF Method. To estimate wind power generation using WRF, we use a version of the model that includes a parameterization of wind turbines that is slightly modified from a previously used approach (12, 19). This parameterization has been shown to be more realistic than previous roughness-based approaches (19). We perform a set of eight sensitivity simulations with different installed capacities of wind turbines that are placed within a contiguous wind farm region of 112,320 km^2 in central Kansas. Installed capacities (in units of $MW_i{\cdot}km^{-2}$) are simulated as an increased integrated quantity of wind turbines deployed to 780 grid cells of 144 km^2 each, which collectively represents the wind farm region. We use values of 0.3125, 0.625, 1.25, 2.5, 5.0, 10, 25, and 100 $MW_i{\cdot}km^{-2}$ for the installed capacities in the simulations and refer to the simulations by these capacities. The wind turbine characteristics are specified using the technical specifications of the Vestas V112 3.0 MW_i in terms of its power, thrust, and standing coefficients (see *SI Appendix* for the detailed model configuration). Note that this model setup does not have sufficient horizontal or vertical resolution to simulate interturbine interactions or wakes within the 12- × 12-km resolution grid cell, but rather uses the turbine specifications and installed capacity to derive one aggregate wind turbine for each grid cell and, where appropriate, the corresponding vertical levels. Additional simulations were performed to evaluate the sensitivity to the horizontal (to 3 km) and vertical spacing (to 24 levels in the lowest 1 km, 6 within the vertical rotor swept height) over a representative time period of June 15–21 and were found to yield comparable results (*SI Appendix*, Fig. 5).

VKE Flux Method. The VKE method expands upon one of the approaches of refs. 10 and 11, where a thought experiment illustrated how considering only wind speeds and turbine specifications can yield generation rates that are physically unrealizable. The method is based on an analytical description of the momentum balance of the wind farm, a central concept used in similar studies on large-scale wind power limits (20–22) or for other forms of renewable energy such as tidal power (23, 24) (detailed methodology is given in *SI Appendix*). It assumes that when wind farms extend tens of kilometers downwind, horizontal kinetic energy has either been extracted from the mean flow by the first few rows of turbines or has been lost to turbulent dissipation, so that the generation rate of wind turbines further downwind is then limited by the downward flux of kinetic energy. For this reason, it is assumed that the horizontal kinetic energy flux can be neglected for large-scale wind farms, allowing us to estimate the maximum extraction rate of kinetic energy by the turbines from the vertical downward flux of kinetic energy from the atmosphere above the wind farm. The model yields an analytic expression for the maximum extraction rate, $P_{max} = (2\sqrt{3}/9) \cdot \rho u_*^2 \cdot v_0$, where ρ is the air density, u_* is the friction velocity at the surface, and v_0 is the wind speed of the control simulation at the 84-m hub height. Note that in addition to the wind speed (v_0), this method uses the surface friction velocity (u_*) as an additional meteorological variable to yield the rate P_{max}. This additional information is not used in common methods that evaluate limits to wind power generation using only wind speeds and a prescribed installed capacity (3–7). We then convert this maximum rate into a limit for electricity generation by using the Betz limit and estimates of wake turbulence (25), resulting in a reduction to about 66%, or two-thirds, of P_{max}. Thus, we define the maximum electricity generation rate by a large wind farm as $P_e = (4\sqrt{3}/27) \cdot \rho u_*^2 \cdot v_0$. This results in the maximum electricity generation rate, P_e, to be equivalent to $(4\sqrt{3}/27) = 26\%$ of the turbulent dissipation occurring before wind farm deployment. Note that P_e is not specific to an installed capacity or wind turbine manufacturer specifications, thereby resulting in the maximum wind power generation rate possible from the pre-turbine climatological vertical kinetic energy flux through hub height.

Results and Discussion

As shown in Fig. 1, the WRF simulations show that a greater installed capacity within the wind farm region increases the total electricity generation rate. This increase is almost linear at the lower installed capacities (0.3 $MW_i{\cdot}km^{-2} \approx 0.13\ W_e{\cdot}m^{-2}$, 0.6 $MW_i{\cdot}km^{-2} \approx 0.24\ W_e{\cdot}m^{-2}$; subscripts i and e refer to the installed capacity and electricity generation, respectively). With further increases in the installed capacity, the marginal return of electricity generation predominantly occurs during higher wind speed periods. Such greater generation rates during windy periods can be seen in the differences between the simulations with 5.0 and 10 $MW_i{\cdot}km^{-2}$ during the high wind speeds of June, whereas the difference is smaller during the lower wind speeds of August and September. Because the greater generation rates occur during periods that are less frequent, the increase in generation is no longer linear. This is reflected by comparing the generated electricity of the 5.0 $MW_i{\cdot}km^{-2}$ to the 0.3 $MW_i{\cdot}km^{-2}$ simulation, which generates seven times more electricity with 16 times as many wind turbines. Stated differently, each wind turbine at 5.0 $MW_i{\cdot}km^{-2}$ generates electricity at half the rate as wind turbines with the same technical specifications but installed at 0.3 $MW_i{\cdot}km^{-2}$.

This difference in the relationship between generation rate and installed capacity is reflected in a change in the capacity factor. First, we use the hub-height wind speeds of the control simulation and the turbine power curve for the Vestas V112 turbine (*SI Appendix*, Fig. 6) to calculate the generation rate of a single isolated wind turbine deployed to each location and time. This yields a capacity factor of 47%, which represents the upper bound value for the case of no interactions between the wind turbines and the atmospheric flow. This estimate compares well to the capacity factors of 22–36% (1, 7) derived from installed capacity and operational generation data from Kansas during 2006–2012, even though this estimate includes turbines of various technical specifications taken over a much longer timescale than this study. Using the 2012 installed capacity of 2,713 MW_i (7) and the area of 213,000 km^2 for Kansas yields a state-scale installed capacity of

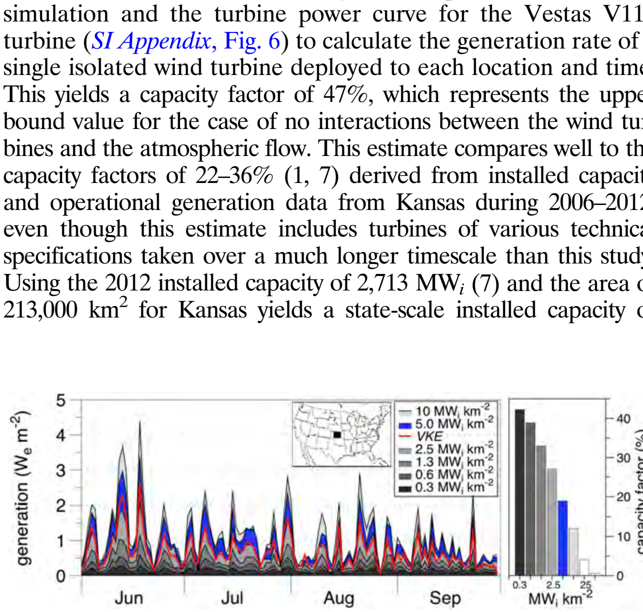

Fig. 1. (*Left*) Simulated daily mean electricity generation rates over the Kansas wind farm region (black square on map) for different installed capacities of up to 10 $MW_i{\cdot}km^{-2}$. The higher installed capacities of 25 and 100 $MW_i{\cdot}km^{-2}$ are not shown, because they often yield less than the 10 $MW_i{\cdot}km^{-2}$ simulation. For comparison, the VKE estimate is shown in red. (*Right*) The mean per-turbine capacity factor derived for the different simulations.

0.013 $MW_i \cdot km^{-2}$, which falls below the lowest installed capacity that we used. Our simulation with the lowest installed capacity of 0.3 $MW_i \cdot km^{-2}$ corresponds to a slightly reduced capacity factor of 42%, and 39% with 0.6 $MW_i \cdot km^{-2}$ (*SI Appendix*, Table 2). These capacity factors compare well with the previously used values for this region of 37% (6) and 40–47% used by the National Renewable Energy Laboratory (7). However, the estimates of refs. 6 and 7 used an installed capacity of 5.0 $MW_i \cdot km^{-2}$, which in our simulations yield a much lower capacity factor of 19%, which should thus result in much lower estimates for wind power generation.

The reduction in capacity factor with greater installed capacity results from an enhanced interaction of wind turbines with the atmospheric flow. Because a greater installed capacity of wind turbines removes more kinetic energy from the atmosphere and converts it into electric energy, this causes a decrease in the hub-height wind speed downwind (26), which decreases the mean per-turbine electricity generation rate of the wind farm. This reduction in wind speeds within the wind farm and its effects on the per-turbine electricity generation rate is shown in Fig. 2 in relation to the power curve of the turbine and the wind speed histogram (Fig. 2*A*) as well as the mean wind speed and mean per-turbine generation rate (Fig. 2*B*). The point spread around the 3.0 MW_i turbine power curve in Fig. 2*A*, with some values below the 3.0 $m \cdot s^{-1}$ cut-in wind speed, is due to the use of mean hourly hub-height wind speed and electricity generation rate for the entire wind farm region. Additionally, the variability in hub-height wind speed decreases with greater installed capacity (Fig. 2*B*), which also decreases the variability of per-turbine electricity generation. This reduction in wind speeds has also been observed in previous modeling studies (9–12, 27, 28).

Fig. 2*C* shows the increasing importance of considering the reduction in wind speed for the mean generation rate of the wind farm with greater installed capacity. The dashed line in Fig. 2*C* is derived by applying the turbine power curve to the control hub-height wind speeds for a mean per-turbine capacity factor of 47% (slope = 0.47). The WRF simulations with installed capacities of less than about 1 $MW_i \cdot km^{-2}$ yield similar estimates because the capacity factors remain high (see also *SI Appendix*, Table 2). At greater installed capacities, the WRF simulations resulted in proportionally lower estimates. For example, at an installed capacity of 2.5 $MW_i \cdot km^{-2}$ the "no interactions" estimate would yield a generation rate per unit area of the wind farm of 1.18 $W_e \cdot m^{-2}$, but this was simulated to be 0.68 $W_e \cdot m^{-2}$. This discrepancy continues with greater installed capacities, so at 5.0 $MW_i \cdot km^{-2}$ the estimate without interactions overestimates the average electricity generation rate by more than a factor of two (2.4 $W_e \cdot m^{-2}$ for no interactions, 0.95 $W_e \cdot m^{-2}$ with interactions). The maximum electricity generation rate of 1.1 $W_e \cdot m^{-2}$ is obtained with an installed capacity of 10 $MW_i \cdot km^{-2}$, at which the associated hub-height wind speed decreased by 42% and the capacity factor is reduced to 12%. Our WRF simulations suggest that previous estimates of mean wind energy generation potentials for Kansas of 1.9 $W_e \cdot m^{-2}$ (6), 2.0–2.4 $W_e \cdot m^{-2}$ (7), and 2.5 $W_e \cdot m^{-2}$ (4) are likely to be too high because the effects of reduced wind speeds were not considered. To place this reduction into the context of present-day wind power deployment, note that such installed capacities are several orders of magnitude larger than presently operational Kansas wind farms. Our simulations thus suggest that an equidistant deployment of 50 times more installed wind power in Kansas than is presently operational ($\approx$ 0.013–0.6 $MW_i \cdot km^{-2}$) would maintain the presently high per-turbine capacity factors and thus increase the generation rate 50-fold.

The VKE method captures the magnitude of wind power generation as well as its temporal variations. In our Kansas scenario, we estimate a maximum 4-mo mean generation rate from WRF at 10 $MW_i \cdot km^{-2}$ as 1.1 $W_e \cdot m^{-2}$ and VKE as 0.64 $W_e \cdot m^{-2}$. Based on the linear correlation, the daily mean estimates of the two methods are highly correlated: $r^2 = 0.98$, with a slope of $m = 1.76$, an rmse of 0.60, and a mean absolute error (MAE) of 0.47. The WRF estimate from the 5.0 $MW_i \cdot km^{-2}$ simulation, an installed capacity often used for wind power planning and policy analysis (6), also compares very well, with daily mean estimates being highly correlated with VKE with $r^2 = 0.98$, $m = 1.47$, rmse = 0.39, and MAE = 0.32. The mean generation rate of this WRF simulation was 0.95 $W_e \cdot m^{-2}$, nearly the same rate as the 10 $MW_i \cdot km^{-2}$ simulation, but from half the number of turbines. When hourly estimates of WRF and VKE are compared (Fig. 3), we note that correlations are very high during day and night, but the slope is much better captured by VKE during the day, whereas at night VKE underestimates the magnitude of electricity generation by almost 45% in this simulation.

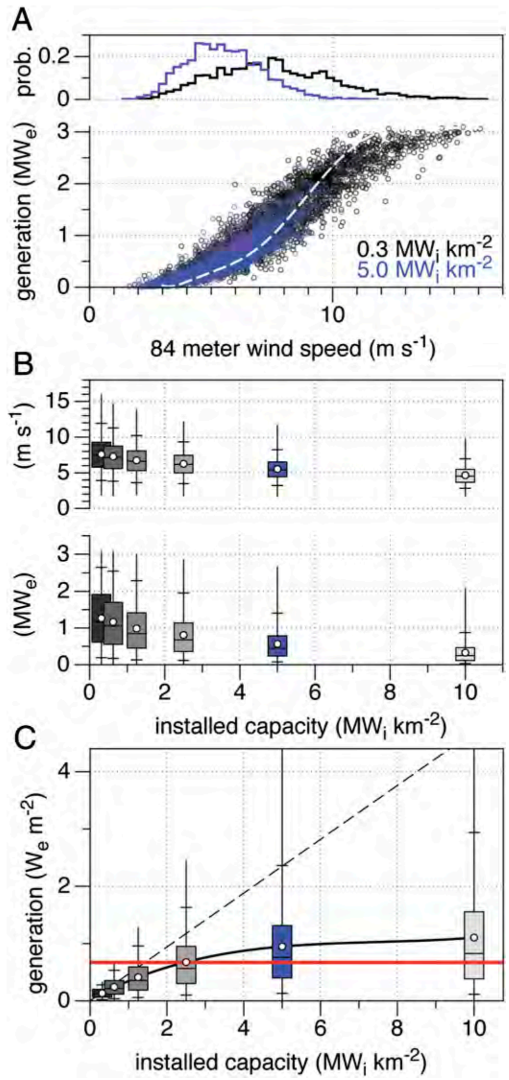

Fig. 2. (*A*) The per-turbine electricity generation rate for two select WRF simulations as a function of hub-height wind speed at 84 m as well as its histogram (*Top*). The dashed line shows the Vestas V112 3.0 MW_i power curve of a single turbine. (*B*) Mean per-turbine generation rate and the 84 m mean hub-height wind speed of the wind farm region as a function of installed capacity. (*C*) Mean per-turbine electricity generation rate as a function of installed capacity when the capacity factor of a single turbine is extrapolated to high installed capacities (dashed line, "no interactions") and the relationship derived from the WRF simulations (solid line, "interactions"). The red line shows the VKE estimate. All box-whisker plots show the 5, 25, 50, 75, and 95% values, with the extent showing the minimum–maximum and the circles showing the mean.

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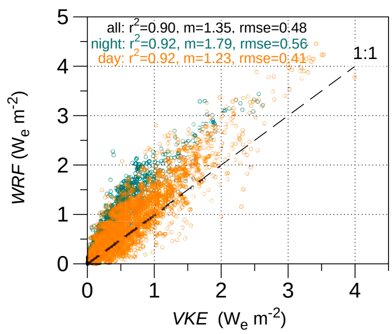

Fig. 3. Comparison of hourly mean electricity generation rates for the wind farm region estimated by VKE and WRF with an installed capacity of 5 $MW_i{\cdot}km^{-2}$.

We attribute this underestimation of wind power generation by VKE at night to its use of the preturbine downward kinetic energy flux of the control. The atmospheric flow in this region typically decouples from the stable surface conditions at night in the summer, which leads to the formation of the low-level jet (LLJ) near the surface (29). The typical nighttime structure of the LLJ (Fig. 4*B*) with a mean stable boundary layer height of 40 m (12–124 m, 5th–95th percentile, respectively) from June–September 2001 in the WRF control mean is consistent with height observations of about 50–350 m in southeastern Kansas during October 1999 (30). Observed LLJ maxima at about 100 m after sunset with an increase in height to about 225 m over the course of the night were also observed for this region on October 25, 1999 (30). The rotors of the wind turbines extend from 28 to 140 m in height and thus reside above, within, or at the upper boundary of the stable boundary layer. The wind turbines in the WRF simulations can thus sometimes directly use the kinetic energy from above the constant stress layer and the LLJ at night. This increased utilization of kinetic energy of the LLJ and the flow of the free atmosphere results in an increased downward kinetic energy and thus a greater maximum generation rate in WRF compared with the VKE method, which does not account for this effect. Based on the nighttime hourly mean values for the wind farm region, a hub-height speed of 9.5 $m{\cdot}s^{-1}$ and a surface momentum flux of 0.15 $kg{\cdot}m^{-1}{\cdot}s^{-2}$ yields a downward kinetic energy flux of 1.39 $W{\cdot}m^{-2}$ with an associated maximum generation rate of 0.36 $W_e{\cdot}m^{-2}$ by VKE. Daytime atmospheric conditions are different. The daytime mean convective boundary layer height in the WRF control simulation is 1,268 m. Of this total height, the constant stress layer, the vertical depth over which the downward kinetic energy flux is considered negligible, typically constitutes the lowest 10% of the convective boundary layer (31, 32). Therefore, during the daytime, the upper extent of the turbine rotors is likely to be within the constant stress layer. Based on mean daytime values, a hub-height speed of 6.9 $m{\cdot}s^{-1}$ and a surface momentum flux of 0.37 $kg{\cdot}m^{-1}{\cdot}s^{-2}$ yields a downward kinetic energy flux of 2.55 $W{\cdot}m^{-2}$ with an associated maximum generation rate of 0.65 $W_e{\cdot}m^{-2}$ by VKE. Note how the daytime VKE estimate is about double the nighttime estimate, even though the wind speed during the daytime is lower. These differences between the nighttime and daytime downward kinetic energy fluxes also help explain the similarities and discrepancies between the daytime and nighttime VKE and WRF estimates (Fig. 3).

One last point to note is that the maximum mean electricity generation rate of 1.1 $W_e{\cdot}m^{-2}$ achieved in WRF has notable effects on the atmosphere and would likely induce considerable differences in climate. Although several recent studies evaluated how wind power generation caused climatic differences in measurements (33, 34) and modeling (10, 12, 13, 27, 35–37), the reduction of wind speeds is relevant here, because this reduction sets the large-scale limit to wind power generation. The mean hub-height wind speed in the 10 $MW_i{\cdot}km^{-2}$ decreased by 42% compared with the control (Fig. 2*B*). This decrease is consistent with VKE, which provides an analytic expression for the decrease in wind speed at maximum generation of $(1-\sqrt{3}/3)\cdot v_0 = 42\%$. As described above, it is this decrease in wind speed with greater kinetic energy extraction by more wind turbines that limits the wind power generation at large scales. That VKE reproduces the decrease in v_0 very well is likely the reason why it captures the magnitude and temporal dynamics of limits to large-scale wind power generation of the WRF simulation.

Interpretation

Our estimates from both methods are compared with several other recent studies in Fig. 5. There is a clear discrepancy between estimates based on climatological wind speeds (black symbols) from estimates derived with atmospheric models (colored symbols), which are generally lower. We attribute these discrepancies to the inclusion of turbine–atmosphere interactions in the case of the atmospheric models that result in the reduction of wind speeds in the wind farm. However, one study included in Fig. 5 was derived from existing operational wind farms and observed generation rates, which calls for a more detailed explanation of the discrepancy between those and our estimates. Numerous footprints of operational wind farms in the United Kingdom were digitized (38) and compared with their documented generation rate, thereby inherently including turbine–atmosphere interactions. With the majority of the wind farms used in ref. 38 covering relatively small areas of about 2.4 km^2 (0.1–13 km^2) of "footprint area" in hilltop or offshore locations, the wind farms have a mean generation rate of about

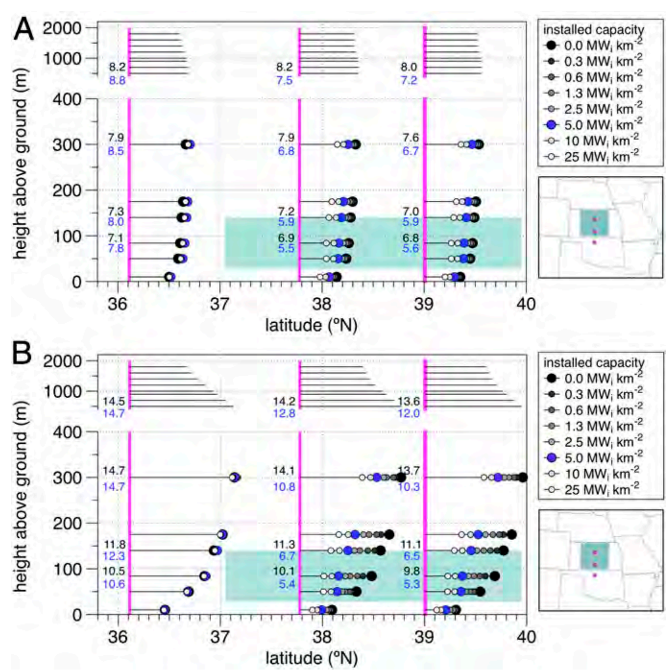

Fig. 4. Mean (*A*) daytime and (*B*) nighttime wind speeds for three selected locations across the wind farm region (*Inset*) for the control and seven WRF simulations with different installed capacities with one location generally upwind and two locations within the wind farm region. The teal boxes show the spatial and vertical extent of the wind farm. The pink bars and dots show the spatial locations where the mean wind speeds were taken. Wind speeds at the hub height of 84 m and top-of-rotor height of 140, 300, and 500 m for the three locations are noted as text for the control (black numbers) and 5.0 $MW_i{\cdot}km^{-2}$ (blue numbers). Note the break in both *y* axes.

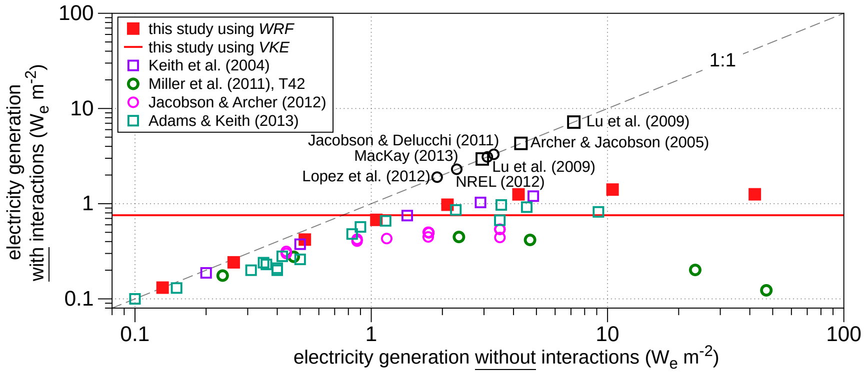

Fig. 5. Regional (squares) and continental-to global scale (circles) large-scale electricity generation estimates in relation to the effect of turbine–atmosphere interactions. The estimates represented by black squares and circles used preturbine wind speeds without including turbine–atmosphere interactions and are placed on the 1:1 line for reference. The colored points refer to estimates based on atmospheric models. These estimates simulate wind speeds and include turbine–atmosphere interactions (*y* axis). The value on the x axis was derived from using the turbine power curve, installed capacity, and the wind speeds of the control simulation. The horizontal line at 0.64 $W_e \cdot m^2$ with interactions is the VKE estimate for Kansas (based on figure 4 from ref. 12 with additional studies and the VKE estimate added).

2.9 $W_e \cdot m^{-2}$ (0.8–6.6 $W_e \cdot m^{-2}$) from a mean installed capacity of about 11 $MW_i \cdot km^{-2}$ (3.5–24 $MW_i \cdot km^{-2}$). These generation rates are substantially higher than our 1.1 $W \cdot m^{-2}$ limit of large-scale wind power generation in Kansas, although the size of the wind farms is also notably smaller.

This difference in wind power generation rates can be understood by relating the kinetic energy used by the wind turbines to their sources. For this, we distinguish between the import of kinetic energy by horizontal and vertical fluxes into the wind farm region. These two contributions change as the spatial scale of the wind farm increases. This change can be illustrated by using the mean values of the wind farm region from the WRF control simulation over the 4-mo period. The mean horizontal flux of kinetic energy is given by $KE_{in,h} = (1/2)\rho v_0^3 \cdot x \cdot h$, where $\rho = 1.1$ $kg \cdot m^{-3}$ is the air density at hub height, $v_0 = 8.0$ $m \cdot s^{-1}$ is the hub-height wind speed at 84 m, $x = 360{,}000$ m is the east–west extent of the wind farm that is perpendicular to the mean wind direction, and $h = 112$ m is the height of the wind farm, assumed here to be equivalent to the rotor diameter of the 3.0 MW_i turbine. This yields a mean horizontal kinetic energy flux of $KE_{in,h} = 11$ GW (or 282 $W \cdot m^{-2}$ per unit cross-sectional area) into the upwind vertical cross-section of the wind farm region. The mean vertical kinetic energy flux is given by $KE_{in,v} = \rho u_*^2 \cdot v_0 \cdot x \cdot y$, where the mean (spatial and temporal) friction velocity at the surface $u_* = 0.45$ $m \cdot s^{-1}$ and $y = 312{,}000$ m is the north–south extent of the wind farm that describes the downwind length of the wind farm. This yields a mean vertical kinetic energy flux downward into the entire wind farm region of $KE_{in,v} = 200$ GW or 1.8 $W \cdot m^{-2}$ per unit surface area of the wind farm region, so that in the Kansas setup, $KE_{in,v}$ provides about 20 times as much kinetic energy as the horizontal influx. Note that this vertical flux of kinetic energy, derived from the WRF control simulation, served as the input to the VKE estimate. When the wind farm increases in downwind length with a greater value of *y*, the contribution by the vertical kinetic energy flux into the wind farm region increases linearly whereas the horizontal contribution remains relatively unchanged. WRF simulations with an installed capacity of 1 $MW_i \cdot km^{-2}$ or greater (>110 GW_i) represent wind farms in which the installed capacity is of the order of the mean kinetic energy flux into the wind farm region (about 211 GW), which is when the reductions of wind speed start to play a role in shaping the generation rate.

In the context of the Kansas wind farm region, we can use these considerations to estimate the downwind depth at which the horizontal kinetic energy flux is fully consumed by electricity generation and turbulence. Assuming a conservative 33% loss to turbulence during the extraction process (25), the 11-GW mean horizontal kinetic energy flux would result in a maximum electricity generation rate of 7.4 GW_e. This generation rate is equivalent to about 5,800 wind turbines of 3.0 MW_i capacity with a 42% capacity factor, which is close to our WRF simulation at the lowest installed capacity of 0.3 $MW_i \cdot km^{-2}$. When considering the much greater installed capacity of 5.0 $MW_i \cdot km^{-2}$, the 11 GW of horizontal kinetic energy flux would be fully consumed within a downwind depth of about 10 km (see also ref. 22). Therefore, as the downwind extent of the wind farm grows, electricity generation rates of successive downwind turbines are derived progressively less from the horizontal flux and more from the vertical flux. This results in an edge effect of higher generation rates at the upwind border of the wind farm compared with lower generation rates in the interior of the wind farm region (see also *SI Appendix*, Fig. 9). This edge effect does not exist for the VKE estimate (*SI Appendix*, Fig. 9), because it neglects the horizontal kinetic energy flux as an energy source. This can in part explain the lower estimates of the VKE method. However, when considering wind farms of greater sizes, the influence of this edge effect on the mean generation rate becomes progressively less important to consider.

Generation rates above those estimated by VKE could be achieved if the incoming horizontal kinetic energy flux is available to the wind farm because it was not extracted by upwind turbines, or relate to an increase in the vertical kinetic energy flux by the wind turbines, as shown to particularly occur in the WRF simulations at night. The spatial extent over which this enhanced vertical kinetic energy flux can be maintained, how much it alters the LLJ, and possibly how this results in a regional redistribution in this flux remain as open questions.

An overall increase in the downward kinetic energy flux at larger deployment scales seems unlikely to occur, because climate model simulations performed at continental and global scales do not predict such an increase for present-day radiative forcing conditions (10, 13). Although these studies did not include a full analysis of the energetics, their predictions broadly agree with the predictions of the VKE method in terms of a maximum of 25–27% of the natural dissipation rate that could be used for electricity generation (10) and a slowdown of hub-height wind velocities by 51% globally, 50% over land, and 51% over the ocean (13). Despite its lack of considering changes in the downward kinetic energy flux, it would nevertheless seem that the VKE method is suitable to provide first-order estimates of the magnitude of wind power generation by large wind farms, but this would require further confirmation.

This agreement does not resolve the apparent discrepancy between our estimates and the observation-based estimates from small UK wind farms (38); note that these wind farms have downwind depths much less than 10 km, making their electricity generation rates almost exclusively dependent on the horizontal kinetic energy flux. Formulated differently, edge effects determine the generation rate of these small wind farms. To illustrate compatibility with WRF-simulated results, we apply the footprint area definition of ref. 38 for isolated 3.0 MW_i wind turbines (i.e., a circle with diameter five times the turbine diameter, or 0.25 km^2 per turbine) to our simulation of 0.3 $MW_i \cdot km^{-2}$. This results in each 3.0 MW_i turbine being spaced 3.1 km apart and yields a comparable

5.1 $W_e{\cdot}m^{-2}$ for the turbines. For progressively larger installed capacities, this estimate decreases to 4.7 $W_e{\cdot}m^{-2}$ for an installed capacity of 0.6 $MW_i{\cdot}km^{-2}$, to 4.0 $W_e{\cdot}m^{-2}$ for 1.3 $MW_i{\cdot}km^{-2}$, to 3.3 $W_e{\cdot}m^{-2}$ for 2.5 $MW_i{\cdot}km^{-2}$, to 2.3 $W_e{\cdot}m^{-2}$ for 5.0 $MW_i{\cdot}km^{-2}$, and to 1.3 $W_e{\cdot}m^{-2}$ for 10 $MW_i{\cdot}km^{-2}$.

In summary, these considerations illustrate the strong dependence of small-scale wind farms on a horizontal kinetic energy flux that is not influenced by other wind farms upwind. Our results suggest that expanding wind farms to large scales will limit generation rates by the vertical kinetic energy flux, thereby constraining mean large-scale generation rates to about 1 $W_e{\cdot}m^{-2}$ even in windy regions. Large-scale estimates that exceed 1 $W_e{\cdot}m^{-2}$ thus seem to be inconsistent with the physical limits of kinetic energy generation and transport within the Earth's atmosphere.

Conclusion

We evaluated large-scale limits to wind power generation in a hypothetical scenario of a large wind farm in Kansas using two distinct methods. We first used the WRF regional atmospheric model in which the wind farm interacts with the atmospheric flow to derive the maximum wind power generation rate of about 1.1 $W_e{\cdot}m^{-2}$. This maximum rate results from a trade-off by which a greater installed capacity resulted in a greater reduction of wind speeds within the wind farm. This reduction in wind speeds reflects the strong interaction of the wind farm with the atmospheric flow, with speeds reduced by 42% at the maximum generation rate. We then showed that these estimates can also be derived by the VKE method, which used the downward influx of kinetic energy of the control climatology and its partitioning into turbulent dissipation and wind-energy generation as a basis. The VKE method predicts that the maximum generation rate equals 26% of the instantaneous downward transport of kinetic energy through hub height. This method only required the information of wind speeds and friction velocity of the control climate to provide an estimate of a maximum wind power generation rate. With an estimate of 0.64 $W_e{\cdot}m^{-2}$, the VKE method underestimates the maximum wind power generation rate, particularly during night, but it nevertheless captures the temporal dynamics as well as the reduction in wind speeds very well.

Both methods used here yield estimates for the limits to large-scale wind power generation that are energetically consistent. Although many current wind farms are still comparatively small and can therefore sustain greater generation rates, an energetically consistent approach becomes relevant when the installed capacity of the wind farm approaches the kinetic energy flux into the wind farm region. Although the VKE method assumes this influx to be fixed, it nevertheless demonstrates that an energetically consistent estimate can be done in a comparatively simple way, thus providing a useful means to derive a first-order estimate of large-scale wind power generation from preturbine climatologies. We conclude that large-scale wind power generation is thus limited to a maximum of about 1 $W_e{\cdot}m^{-2}$ because of this inevitable reduction of wind speeds and the comparatively low vertical kinetic energy fluxes in the atmosphere.

ACKNOWLEDGMENTS. We thank C. Dhara, M. Renner, N. Carvalhais, two anonymous reviewers, and the editor for their suggestions and constructive comments that helped improve the mansucript. This study was funded by the Max Planck Society through the Max Planck Research Group of A.K. A.J.M. was funded by the National Science Foundation.

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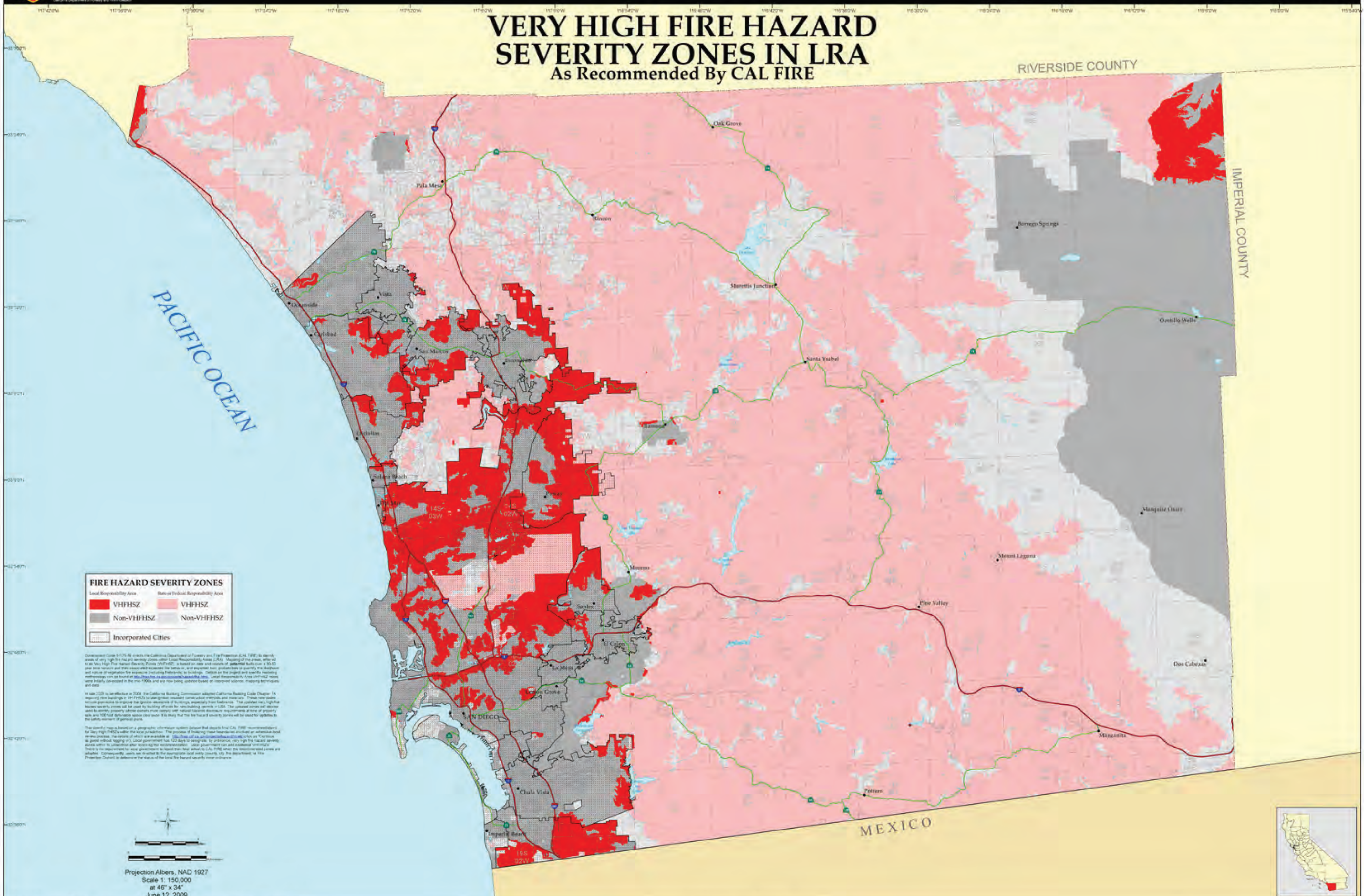
EXHIBIT
4

SAN DIEGO COUNTY



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DATA SOURCES
CAL FIRE Fire Hazard Severity Zones (FHSZL06_3)
CAL FIRE State Responsibility Areas (SRA05_5)
CAL FIRE Incorporated Cities (Incorp07_3)
PLSS (1:100,000 USGS, Land Grants with CAL FIRE grid)

EXHIBIT
5

SEE COMMENTARY

Anthropogenic warming has increased drought risk in California

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Edited by Jane Lubchenco, Oregon State University, Corvallis, OR, and approved January 30, 2015 (received for review November 22, 2014)

California is currently in the midst of a record-setting drought. The drought began in 2012 and now includes the lowest calendar-year and 12-mo precipitation, the highest annual temperature, and the most extreme drought indicators on record. The extremely warm and dry conditions have led to acute water shortages, groundwater overdraft, critically low streamflow, and enhanced wildfire risk. Analyzing historical climate observations from California, we find that precipitation deficits in California were more than twice as likely to yield drought years if they occurred when conditions were warm. We find that although there has not been a substantial change in the probability of either negative or moderately negative precipitation anomalies in recent decades, the occurrence of drought years has been greater in the past two decades than in the preceding century. In addition, the probability that precipitation deficits co-occur with warm conditions and the probability that precipitation deficits produce drought have both increased. Climate model experiments with and without anthropogenic forcings reveal that human activities have increased the probability that dry precipitation years are also warm. Further, a large ensemble of climate model realizations reveals that additional global warming over the next few decades is very likely to create ∼100% probability that any annual-scale dry period is also extremely warm. We therefore conclude that anthropogenic warming is increasing the probability of co-occurring warm–dry conditions like those that have created the acute human and ecosystem impacts associated with the "exceptional" 2012–2014 drought in California.

drought | climate extremes | climate change detection | event attribution | CMIP5

The state of California is the largest contributor to the economic and agricultural activity of the United States, accounting for a greater share of population (12%) (1), gross domestic product (12%) (2), and cash farm receipts (11%) (3) than any other state. California also includes a diverse array of marine and terrestrial ecosystems that span a wide range of climatic tolerances and together encompass a global biodiversity "hotspot" (4). These human and natural systems face a complex web of competing demands for freshwater (5). The state's agricultural sector accounts for 77% of California water use (5), and hydroelectric power provides more than 9% of the state's electricity (6). Because the majority of California's precipitation occurs far from its urban centers and primary agricultural zones, California maintains a vast and complex water management, storage, and distribution/conveyance infrastructure that has been the focus of nearly constant legislative, legal, and political battles (5). As a result, many riverine ecosystems depend on mandated "environmental flows" released by upstream dams, which become a point of contention during critically dry periods (5).

California is currently in the midst of a multiyear drought (7). The event encompasses the lowest calendar-year and 12-mo precipitation on record (8), and almost every month between December 2011 and September 2014 exhibited multiple indicators of drought (Fig. S1). The proximal cause of the precipitation deficits was the recurring poleward deflection of the cool-season storm track by a region of persistently high atmospheric pressure, which steered Pacific storms away from California over consecutive seasons (8–11). Although the extremely persistent high pressure is at least a century-scale occurrence (8), anthropogenic global warming has very likely increased the probability of such conditions (8, 9).

Despite insights into the causes and historical context of precipitation deficits (8–11), the influence of historical temperature changes on the probability of individual droughts has—until recently—received less attention (12–14). Although precipitation deficits are a prerequisite for the moisture deficits that constitute "drought" (by any definition) (15), elevated temperatures can greatly amplify evaporative demand, thereby increasing overall drought intensity and impact (16, 17). Temperature is especially important in California, where water storage and distribution systems are critically dependent on winter/spring snowpack, and excess demand is typically met by groundwater withdrawal (18–20). The impacts of runoff and soil moisture deficits associated with warm temperatures can be acute, including enhanced wildfire risk (21), land subsidence from excessive groundwater withdrawals (22), decreased hydropower production (23), and damage to habitat of vulnerable riparian species (24).

Recent work suggests that the aggregate combination of extremely high temperatures and very low precipitation during the 2012–2014 event is the most severe in over a millennium (12). Given the known influence of temperature on drought, the fact that the 2012–2014 record drought severity has co-occurred with record statewide warmth (7) raises the question of whether long-term warming has altered the probability that precipitation deficits yield extreme drought in California.

Significance

California ranks first in the United States in population, economic activity, and agricultural value. The state is currently experiencing a record-setting drought, which has led to acute water shortages, groundwater overdraft, critically low streamflow, and enhanced wildfire risk. Our analyses show that California has historically been more likely to experience drought if precipitation deficits co-occur with warm conditions and that such confluences have increased in recent decades, leading to increases in the fraction of low-precipitation years that yield drought. In addition, we find that human emissions have increased the probability that low-precipitation years are also warm, suggesting that anthropogenic warming is increasing the probability of the co-occurring warm–dry conditions that have created the current California drought.

Author contributions: N.S.D., D.L.S., and D.T. designed research, performed research, contributed new reagents/analytic tools, analyzed data, and wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

See Commentary on page 3858.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1422385112/-/DCSupplemental.

SUSTAINABILITY SCIENCE

Results

We analyze the "Palmer" drought metrics available from the US National Climatic Data Center (NCDC) (25). The NCDC Palmer metrics are based on the Palmer Drought Severity Index (PDSI), which uses monthly precipitation and temperature to calculate moisture balance using a simple "supply-and-demand" model (26) (*Materials and Methods*). We focus on the Palmer Modified Drought Index (PMDI), which moderates transitions between wet and dry periods (compared with the PDSI) (27). However, we note that the long-term time series of the PMDI is similar to that of other Palmer drought indicators, particularly at the annual scale (Figs. S1 and S2).

Because multiple drought indicators reached historic lows in July 2014 (Figs. S1–S3), we initially focus on statewide PMDI, temperature, and precipitation averaged over the August–July 12-mo period. We find that years with a negative PMDI anomaly exceeding –1.0 SDs (hereafter "1-SD drought") have occurred approximately twice as often in the past two decades as in the preceding century (six events in 1995–2014 = 30% of years; 14 events in 1896–1994 = 14% of years) (Fig. 1*A* and Fig. S4). This increase in the occurrence of 1-SD drought years has taken place without a substantial change in the probability of negative precipitation anomalies (53% in 1896–2014 and 55% in 1995–2014) (Figs. 1*B* and 2 *A* and *B*). Rather, the observed doubling of the occurrence of 1-SD drought years has coincided with a doubling of the frequency with which a negative precipitation year produces a 1-SD drought, with 55% of negative precipitation years in 1995–2014 co-occurring with a –1.0 SD PMDI anomaly, compared with 27% in 1896–1994 (Fig. 1 *A* and *B*).

Most 1-SD drought years have occurred when conditions were both dry (precipitation anomaly < 0) and warm (temperature anomaly > 0), including 15 of 20 1-SD drought years during 1896–2014 (Fig. 2*A* and Fig. S4) and 6 of 6 during 1995–2014 (Fig. 2*B* and Fig. S4). Similarly, negative precipitation anomalies are much more likely to produce 1-SD drought if they co-occur with a positive temperature anomaly. For example, of the 63 negative precipitation years during 1896–2014, 15 of the 32 warm–dry years (47%) produced 1-SD drought, compared with only 5 of the 31 cool–dry years (16%) (Fig. 2*A*). (During 1896–1994, 41% of warm–dry years produced 1-SD droughts, compared with 17% of cool–dry years.) The probability that a negative precipitation anomaly co-occurs with a positive temperature anomaly has increased recently, with warm–dry years occurring more than twice as often in the past two decades (91%) as in the preceding century (42%) (Fig. 1*B*).

All 20 August–July 12-mo periods that exhibited a –1.0 SD PMDI anomaly also exhibited a –0.5 SD precipitation anomaly (Fig. 1*B* and 2*E*), suggesting that moderately low precipitation is prerequisite for a 1-SD drought year. However, the occurrence of –0.5 SD precipitation anomalies has not increased in recent years (40% in 1896–2014 and 40% in 1995–2014) (Fig. 2 *A* and *B*). Rather, these moderate precipitation deficits have been far more likely to produce 1-SD drought when they occur in a warm year. For example, during 1896–2014, 1-SD drought occurred in 15 of the 28 years (54%) that exhibited both a –0.5 SD precipitation anomaly and a positive temperature anomaly, but in only 5 of the 20 years (25%) that exhibited a –0.5 SD precipitation anomaly and a negative temperature anomaly (Fig. 2*A*). During 1995–2014, 6 of the 8 moderately dry years produced 1-SD drought (Fig. 1*A*), with all 6 occurring in years in which the precipitation anomaly exceeded –0.5 SD and the temperature anomaly exceeded 0.5 SD (Fig. 1*C*).

Taken together, the observed record from California suggests that (*i*) precipitation deficits are more likely to yield 1-SD PMDI droughts if they occur when conditions are warm and (*ii*) the occurrence of 1-SD PMDI droughts, the probability of precipitation deficits producing 1-SD PMDI droughts, and the probability of precipitation deficits co-occurring with warm conditions have all been greater in the past two decades than in the preceding century.

These increases in drought risk have occurred despite a lack of substantial change in the occurrence of low or moderately low precipitation years (Figs. 1*B* and 2 *A* and *B*). In contrast, statewide warming (Fig. 1*C*) has led to a substantial increase in warm conditions, with 80% of years in 1995–2014 exhibiting a positive temperature anomaly (Fig. 2*B*), compared with 45% of years in 1896–2014 (Fig. 2*A*). As a result, whereas 58% of moderately dry years were warm during 1896–2014 (Fig. 2*A*) and 50% were warm during 1896–1994, 100% of the 8 moderately dry years in 1995–2014 co-occurred with a positive temperature anomaly (Fig. 2*B*). The observed statewide warming (Fig. 1*C*) has therefore substantially increased the probability that when moderate precipitation deficits occur, they occur during warm years.

The recent statewide warming clearly occurs in climate model simulations that include both natural and human forcings ("Historical" experiment), but not in simulations that include only natural forcings ("Natural" experiment) (Fig. 3*B*). In particular, the Historical and Natural temperatures are found to be different at the 0.001 significance level during the most recent 20-, 30-, and 40-y periods of the historical simulations (using the block bootstrap resampling applied in ref. 28). In contrast, although the Historical experiment exhibits a slightly higher mean annual precipitation (0.023 significance level), there is no statistically

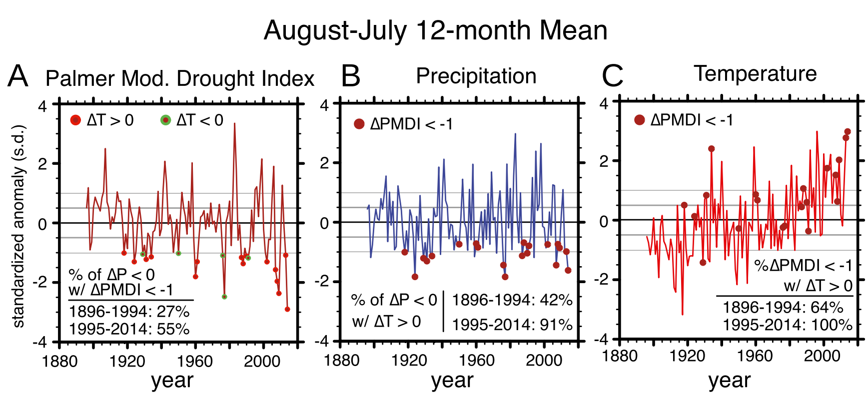

Fig. 1. Historical time series of drought (*A*), precipitation (*B*), and temperature (*C*) in California. Values are calculated for the August–July 12-mo mean in each year of the observed record, beginning in August 1895. In each year, the standardized anomaly is expressed as the magnitude of the anomaly from the long-term annual mean, divided by the SD of the detrended historical annual anomaly time series. The PMDI is used as the primary drought indicator, although the other Palmer indicators exhibit similar historical time series (Figs. S1 and S2). Circles show the years in which the PMDI exhibited a negative anomaly exceeding –1.0 SDs, which are referred to as 1-SD drought years in the text.

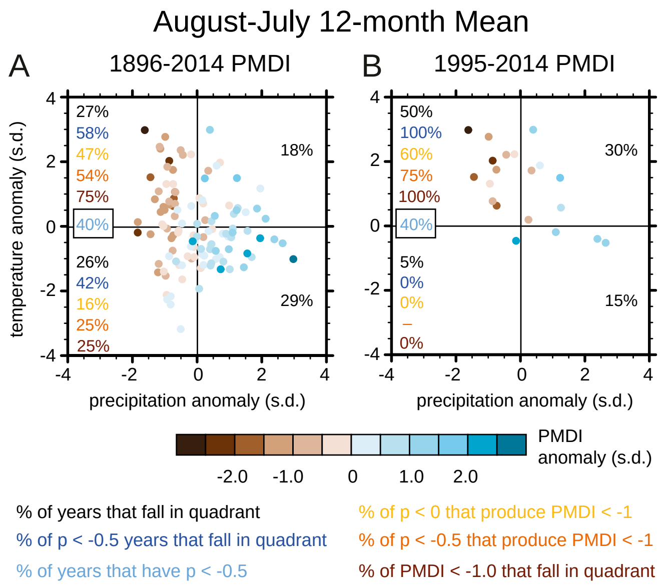

Fig. 2. Historical occurrence of drought, precipitation, and temperature in California. Standardized anomalies are shown for each August–July 12-mo period in the historical record (calculated as in Fig. 1). Anomalies are shown for the full historical record (*A*) and for the most recent two decades (*B*). Percentage values show the percentage of years meeting different precipitation and drought criteria that fall in each quadrant of the temperature–precipitation space. The respective criteria are identified by different colors of text.

significant difference in probability of a –0.5 SD precipitation anomaly (Fig. 3 *A* and *C*). However, the Historical experiment exhibits greater probability of a –0.5 SD precipitation anomaly co-occurring with a positive temperature anomaly (0.001 significance level) (Fig. 3*D*), suggesting that human forcing has caused the observed increase in probability that moderately dry precipitation years are also warm.

The fact that the occurrence of warm and moderately dry years approaches that of moderately dry years in the last decades of the Historical experiment (Fig. 3 *B* and *C*) and that 91% of negative precipitation years in 1995–2014 co-occurred with warm anomalies (Fig. 1*B*) suggests possible emergence of a regime in which nearly all dry years co-occur with warm conditions. We assess this possibility using an ensemble of 30 realizations of a single global climate model [the National Center for Atmospheric Research (NCAR) Community Earth System Model (CESM1) Large Ensemble experiment ("LENS")] (29) (*Materials and Methods*). Before ~1980, the simulated probability of a warm–dry year is approximately half that of a dry year (Fig. 4*B*), similar to observations (Figs. 1*B* and 2). However, the simulated probability of a warm–dry year becomes equal to that of a dry year by ~2030 of RCP8.5. Likewise, the probabilities of co-occurring 0.5, 1.0 and 1.5 SD warm–dry anomalies become approximately equal to those of 0.5, 1.0, and 1.5 SD dry anomalies (respectively) by ~2030 (Fig. 4*B*).

The probability of co-occurring extremely warm and extremely dry conditions (1.5 SD anomaly) remains greatly elevated throughout the 21st century (Fig. 4*B*). In addition, the number of multiyear periods in which a –0.5 SD precipitation anomaly co-occurs with a 0.5 SD temperature anomaly more than doubles between the Historical and RCP8.5 experiments (Fig. 4*A*). We find similar results using a 12-mo moving average (Fig. 4*C*). As with the August–July 12-mo mean (Fig. 4*B*), the probability of a dry year is approximately twice the probability of a warm–dry year for all 12-mo periods before ~1980 (Fig. 4*C*). However, the occurrence of warm years (including +1.5 SD temperature anomalies) increases after ~1980, reaching 1.0 by ~2030. This increase implies a transition to a permanent condition of ~100% risk that any negative—or extremely negative—12-mo precipitation anomaly is also extremely warm.

The overall occurrence of dry years declines after ~2040 (Fig. 4*C*). However, the occurrence of extreme 12-mo precipitation deficits (–1.5 SD) is greater in 2006–2080 than in 1920–2005 (<0.03 significance level). This detectable increase in extremely low-precipitation years adds to the effect of rising temperatures and contributes to the increasing occurrence of extremely warm–dry 12-mo periods during the 21st century.

All four 3-mo seasons likewise show higher probability of co-occurring 1.5 SD warm–dry anomalies after ~1980, with the probability of an extremely warm–dry season equaling that of an extremely dry season by ~2030 for spring, summer, and autumn, and by ~2060 for winter (Fig. 4*D*). In addition, the probability of a –1.5 SD precipitation anomaly increases in spring ($P < 0.001$) and autumn ($P = 0.01$) in 2006–2080 relative to 1920–2005, with spring occurrence increasing by ~75% and autumn occurrence increasing by ~44%—which represents a substantial and statistically significant increase in the risk of extremely low-precipitation events at both margins of California's wet season. In contrast, there is no statistically significant difference in the probability of a –1.5 SD precipitation anomaly for winter.

Discussion

A recent report by Seager et al. (30) found no significant long-term trend in cool-season precipitation in California during the 20th and early 21st centuries, which is consistent with our

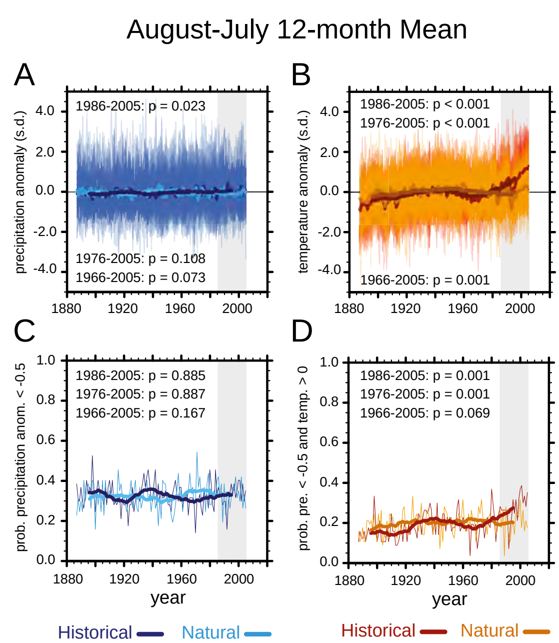

Fig. 3. Influence of anthropogenic forcing on the probability of warm–dry years in California. Temperature and precipitation values are calculated for the August–July 12-mo mean in each year of the CMIP5 Historical and Natural forcing experiments (*Materials and Methods*). The *Top* panels (*A* and *B*) show the time series of ensemble–mean standardized temperature and precipitation anomalies. The *Bottom* panels (*C* and *D*) show the unconditional probability (across the ensemble) that the annual precipitation anomaly is less than –0.5 SDs, and the conditional probability that both the annual precipitation anomaly is less than –0.5 SDs and the temperature anomaly is greater than 0. The bold curves show the 20-y running mean of each annual time series. The CMIP5 Historical and Natural forcing experiments were run until the year 2005. *P* values are shown for the difference between the Historical and Natural experiments for the most recent 20-y (1986–2005; gray band), 30-y (1976–2005), and 40-y (1966–2005) periods of the CMIP5 protocol. *P* values are calculated using the block bootstrap resampling approach of ref. 28 (*Materials and Methods*).

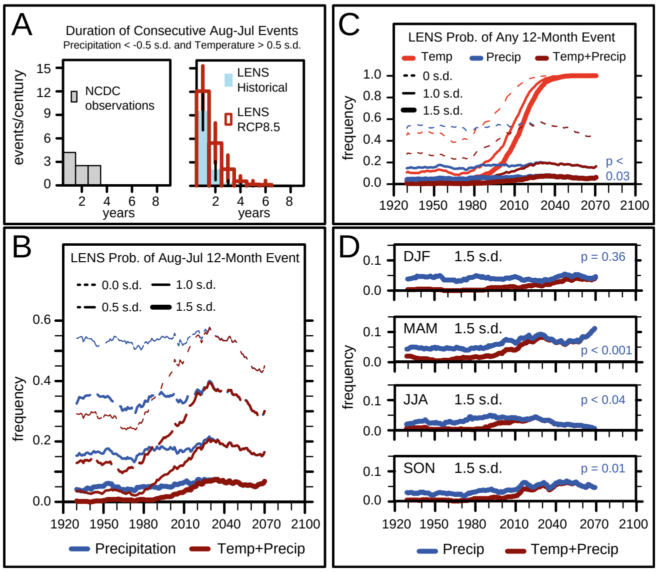

Fig. 4. Projected changes in the probability of co-occurring warm–dry conditions in the 21st century. (*A*) Histogram of the frequency of occurrence of consecutive August–July 12-mo periods in which the 12-mo precipitation anomaly is less than –0.5 SDs and the 12-mo temperature anomaly is at least 0.5 SDs, in historical observations and the LENS large ensemble experiment. (*B*) The probability that a negative 12-mo precipitation anomaly and a positive 12-mo temperature anomaly equal to or exceeding a given magnitude occur in the same August–July 12-mo period, for varying severity of anomalies. (*C*) The probability that a negative precipitation anomaly and a positive temperature anomaly equal to or exceeding a given magnitude occur in the same 12-mo period, for all possible 12-mo periods (using a 12-mo running mean; see *Materials and Methods*), for varying severity of anomalies. (*D*) The unconditional probability of a –1.5 SD seasonal precipitation anomaly (blue curve) and the conditional probability that a –1.5 SD seasonal precipitation anomaly occurs in conjunction with a 1.5 SD seasonal temperature anomaly (red curve), for each of the four 3-mo seasons. Time series show the 20-y running mean of each annual time series. *P* values are shown for the difference in occurrence of –1.5 SD precipitation anomalies between the Historical period (1920–2005) and the RCP8.5 period (2006–2080).

findings. Further, under a scenario of strongly elevated greenhouse forcing, Neelin et al. (31) found a modest increase in California mean December–January–February (DJF) precipitation associated with a local eastward extension of the mean subtropical jet stream west of California. However, considerable evidence (8–11, 31–33) simultaneously suggests that the response of northeastern Pacific atmospheric circulation to anthropogenic warming is likely to be complex and spatiotemporally inhomogeneous, and that changes in the atmospheric mean state may not be reflective of changes in the risk of extreme events (including atmospheric configurations conducive to precipitation extremes). Although there is clearly value in understanding possible changes in precipitation, our results highlight the fact that efforts to understand drought without examining the role of temperature miss a critical contributor to drought risk. Indeed, our results show that even in the absence of trends in mean precipitation—or trends in the occurrence of extremely low-precipitation events—the risk of severe drought in California has already increased due to extremely warm conditions induced by anthropogenic global warming.

We note that the interplay between the existence of a well-defined summer dry period and the historical prevalence of a substantial high-elevation snowpack may create particular susceptibility to temperature-driven increases in drought duration and/or intensity in California. In regions where precipitation exhibits a distinct seasonal cycle, recovery from preexisting drought conditions is unlikely during the characteristic yearly dry spell (34). Because California's dry season occurs during the warm summer months, soil moisture loss through evapotranspiration (ET) is typically high—meaning that soil moisture deficits that exist at the beginning of the dry season are exacerbated by the warm conditions that develop during the dry season, as occurred during the summers of 2013 and 2014 (7).

Further, California's seasonal snowpack (which resides almost entirely in the Sierra Nevada Mountains) provides a critical source of runoff during the low-precipitation spring and summer months. Trends toward earlier runoff in the Sierra Nevada have already been detected in observations (e.g., ref. 35), and continued global warming is likely to result in earlier snowmelt and increased rain-to-snow ratios (35, 36). As a result, the peaks in California's snowmelt and surface runoff are likely to be more pronounced and to occur earlier in the calendar year (35, 36), increasing the duration of the warm-season low-runoff period (36) and potentially reducing montane surface soil moisture (37). Although these hydrological changes could potentially increase soil water availability in previously snow-covered regions during the cool low-ET season (34), this effect would likely be outweighed by the influence of warming temperatures (and decreased runoff) during the warm high-ET season (36, 38), as well as by the increasing occurrence of consecutive years with low precipitation and high temperature (Fig. 4*A*).

The increasing risk of consecutive warm–dry years (Fig. 4*A*) raises the possibility of extended drought periods such as those found in the paleoclimate record (14, 39, 40). Recent work suggests that record warmth could have made the current event the most severe annual-scale drought of the past millennium (12). However, numerous paleoclimate records also suggest that the region has experienced multidecadal periods in which most years were in a drought state (14, 39, 41, 42), albeit less acute than the current California event (12, 39, 41). Although multidecadal ocean variability was a primary cause of the megadroughts of the last millenium (41), the emergence of a condition in which there is ∼100% probability of an extremely warm year (Fig. 4) substantially increases the risk of prolonged drought conditions in the region (14, 39, 40).

A number of caveats should be considered. For example, ours is an implicit approach that analyzes the temperature and precipitation conditions that have historically occurred with low PMDI years, but does not explicitly explore the physical processes that produce drought. The impact of increasing temperatures on the processes governing runoff, baseflow, groundwater, soil moisture, and land-atmosphere evaporative feedbacks over both the historical period and in response to further global warming remains a critical uncertainty (43). Likewise, our analyses of anthropogenic forcing rely on global climate models that do not resolve the topographic complexity that strongly influences California's precipitation and temperature. Further investigation using high-resolution modeling approaches that better resolve the boundary conditions and fine-scale physical processes (44–46) and/or using analyses that focus on the underlying large-scale climate dynamics of individual extreme events (8) could help to overcome the limitations of simulated precipitation and temperature in the current generation of global climate models.

Conclusions

Our results suggest that anthropogenic warming has increased the probability of the co-occurring temperature and precipitation conditions that have historically led to drought in California. In addition, continued global warming is likely to cause a transition to a regime in which essentially every seasonal, annual, and multiannual precipitation deficit co-occurs with historically warm conditions. The current warm–dry event in California—as well as historical observations of previous seasonal, annual, and multiannual warm–dry events—suggests such a regime would substantially increase the risk of severe impacts on human and natural systems. For example, the projected increase in extremely low precipitation and extremely high temperature during spring and autumn has substantial implications for snowpack water storage, wildfire risk, and terrestrial ecosystems (47). Likewise, the projected increase in annual and multiannual warm–dry periods implies increasing risk of the acute water shortages, critical groundwater overdraft, and species extinction potential that have been experienced during the 2012–2014 drought (5, 20).

California's human population (38.33 million as of 2013) has increased by nearly 72% since the much-remembered 1976–1977 drought (1). Gains in urban and agricultural water use efficiency have offset this rapid increase in the number of water users to the extent that overall water demand is nearly the same in 2013 as it was in 1977 (5). As a result, California's per capita water use has declined in recent decades, meaning that additional short-term water conservation in response to acute shortages during drought conditions has become increasingly challenging. Although a variety of opportunities exist to manage drought risk through long-term changes in water policy, management, and infrastructure (5), our results strongly suggest that global warming is already increasing the probability of conditions that have historically created high-impact drought in California.

Materials and Methods

We use historical time series of observed California statewide temperature, precipitation, and drought data from the National Oceanic and Atmospheric Administration's NCDC (7). The data are from the NCDC "nClimDiv" divisional temperature–precipitation–drought database, available at monthly time resolution from January 1895 to the present (7, 25). The NCDC nClimDiv database includes temperature, precipitation, and multiple Palmer drought indicators, aggregated at statewide and substate climate division levels for the United States. The available Palmer drought indicators include PDSI, the Palmer Hydrological Drought Index (PHDI), and PMDI.

PMDI and PHDI are variants of PDSI (25–27, 48, 49). PDSI is an index that measures the severity of wet and dry anomalies (26). The NCDC nClimDiv PDSI calculation is reported at the monthly scale, based on monthly temperature and precipitation (49). Together, the monthly temperature and precipitation values are used to compute the net moisture balance, based on a simple supply-and-demand model that uses potential evapotranspiration (PET) calculated using the Thornthwaite method. Calculated PET values can be very different when using other methods (e.g., Penman–Monteith), with the Thornthwaite method's dependence on surface temperature creating the potential for overestimation of PET (e.g., ref. 43). However, it has been found that the choice of methods in the calculation of PET does not critically influence the outcome of historical PDSI estimates in the vicinity of California (15, 43, 50). In contrast, the sensitivity of the PET calculation to large increases in temperature could make the PDSI inappropriate for calculating the response of drought to high levels of greenhouse forcing (15). As a result, we analyze the NCDC Palmer indicators in conjunction with observed temperature and precipitation data for the historical period, but we do not calculate the Palmer indicators for the future (for future projections of the PDSI, refer to refs. 15 and 40).

Because the PDSI is based on recent temperature and precipitation conditions (and does not include human demand for water), it is considered an indicator of "meterological" drought (25). The PDSI calculates "wet," "dry," and "transition" indices, using the wet or dry index when the probability is 100% and the transition index when the probability is less than 100% (26). Because the PMDI always calculates a probability-weighted average of the wet and dry indices (27), the PDSI and PMDI will give equal values in periods that are clearly wet or dry, but the PMDI will yield smoother transitions between wet and dry periods (25). In this work, we use the PMDI as our primary drought indicator, although we note that the long-term time series of the PMDI is similar to that of the PDSI and PHDI, particularly at the annual scale considered here (Figs. S1 and S2).

We analyze global climate model simulations from phase 5 of the Coupled Model Intercomparison Project (CMIP5) (51). We compare two of the CMIP5 multimodel historical experiments (which were run through 2005): (*i*) the Historical experiment, in which the climate models are prescribed both anthropogenic and nonanthropogenic historical climate forcings, and (*ii*) the Natural experiment, in which the climate models are prescribed only the nonanthropogenic historical climate forcings. We analyze those realizations for which both temperature and precipitation were available from both experiments at the time of data acquisition. We calculate the temperature and precipitation values over the state of California at each model's native resolution using all grid points that overlap with the geographical borders of California, as defined by a high-resolution shapefile (vector digital data obtained from the US Geological Survey via the National Weather Service at www.nws.noaa.gov/geodata/catalog/national/html/us_state.htm).

We also analyze NCAR's large ensemble ("LENS") climate model experiment (29). The LENS experiment includes 30 realizations of the NCAR CESM1. This large single-model experiment enables quantification of the uncertainty arising from internal climate system variability. Although the calculation of this "irreducible" uncertainty likely varies between climate models, it exists independent of uncertainty arising from model structure, model parameter values, and climate forcing pathway. At the time of acquisition, LENS results were available for 1920–2005 in the Historical experiment and 2006–2080 in the RCP8.5 (Representative Concentration Pathway) experiment. The four RCPs are mostly indistinguishable over the first half of the 21st century (52). RCP8.5 has the highest forcing in the second half of the 21st century and reaches ~4 °C of global warming by the year 2100 (52).

Given that the ongoing California drought encompasses the most extreme 12-mo precipitation deficit on record (8) and that both temperature and many drought indicators reached their most extreme historical values for California in July 2014 (7) (Fig. 1 and Figs. S1 and S2), we use the 12-mo August–July period as one period of analysis. However, because severe conditions can manifest at both multiannual and subannual timescales, we also analyze the probability of occurrence of co-occurring warm and dry conditions for multiannual periods, for all possible 12-mo periods, and for the winter (DJF), spring (March–April–May), summer (June–July–August), and autumn (September–October–November) seasons.

We use the monthly-mean time series from NCDC to calculate observed time series of statewide 12-mo values of temperature, precipitation, and PMDI. Likewise, we use the monthly-mean time series from CMIP5 and LENS to calculate simulated time series of statewide 12-mo and seasonal values of temperature and precipitation. From the time series of annual-mean values for each observed or simulated realization, we calculate (*i*) the baseline mean value over the length of the record, (*ii*) the annual anomaly from the baseline mean value, (*iii*) the SD of the detrended baseline annual anomaly time series, and (*iv*) the ratio of each individual annual anomaly value to the SD of the detrended baseline annual anomaly time series. (For the 21st-century simulations, we use the Historical simulation as the baseline.) Our time series of standardized values are thereby derived from the time series of 12-mo annual (or 3-mo seasonal) mean anomaly values that occur in each year.

For the multiannual analysis, we calculate consecutive occurrences of August–July 12-mo values. For the analysis of all possible 12-mo periods, we generate the annual time series of each 12-mo period (January–December, February–January, etc.) using a 12-mo running mean. For the seasonal analysis, we generate the time series by calculating the mean of the respective 3-mo season in each year.

We quantify the statistical significance of differences in the populations of different time periods using the block bootstrap resampling approach of ref. 28. For the CMIP5 Historical and Natural ensembles, we compare the populations of the August–July values in the two experiments for the 1986–2005, 1976–2005, and 1966–2005 periods. For the LENS seasonal analysis, we compare the respective populations of DJF, March–April–May, June–July–August, and September–October–November values in the 1920–2005 and 2006–2080 periods. For the LENS 12-mo analysis, we compare the populations of 12-mo values in the 1920–2005 and 2006–2080 periods, testing block lengths up to 16 to account for temporal autocorrelation out to 16 mo for the 12-mo running mean data. (Autocorrelations beyond 16 mo are found to be negligible.)

Throughout the text, we consider drought to be those years in which negative 12-mo PMDI anomalies exceed −1.0 SDs of the historical interannual PMDI variability. We stress that this value is indicative of the variability of the annual (12-mo) PMDI, rather than of the monthly values (compare Fig. 1 and Figs. S1 and S2). We consider "moderate" temperature and precipitation anomalies to be those that exceed 0.5 SDs ("0.5 SD") and "extreme" temperature and precipitation anomalies to be those that exceed 1.5 SDs ("1.5 SD").

ACKNOWLEDGMENTS. We thank the editor and two anonymous reviewers for insightful comments; Deepti Singh for assistance with the block bootstrap resampling; the National Oceanic and Atmospheric Administration's NCDC for access to the historical temperature, precipitation, and drought data; the World Climate Research Program and Department of Energy's Program for Climate Model Diagnosis and Intercomparison for access to the CMIP5 simulations; and NCAR for access to the LENS simulations. Our work was supported by National Science Foundation Award 0955283 and National Institutes of Health Award 1R01AI090159-01.

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EXHIBIT 6

Indications for Protracted Groundwater Depletion after Drought over the Central Valley of California*,+

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(Manuscript received 1 July 2015, in final form 14 October 2015)

ABSTRACT

Ongoing (2014–16) drought in the state of California has played a major role in the depletion of groundwater. Within California's Central Valley, home to one of the world's most productive agricultural regions, drought and increased groundwater depletion occurs almost hand in hand, but this relationship appears to have changed over the last decade. Data derived from 497 wells have revealed a continued depletion of groundwater lasting a full year after drought, a phenomenon that was not observed in earlier records before the twenty-first century. Possible causes include 1) lengthening of drought associated with amplification in the 4–6-yr drought and El Niño frequency since the late 1990s and 2) intensification of drought and increased pumping that enhances depletion. Altogether, the implication is that current groundwater storage in the Central Valley will likely continue to diminish even further in 2016, regardless of the drought status.

1. Introduction

California's Central Valley is undergoing a groundwater drilling boom amid one of the most severe droughts in state history, and new wells often have to be drilled deeper in order to tap into the shrinking aquifer (Howard 2014; Kennedy 2014). Drought conditions have forced the state of California to consider new methods and regulations regarding the monitoring and appropriation of groundwater resources (AghaKouchak et al. 2014b). Satellite monitoring of the Gravity Recovery and Climate Experiment (GRACE) has indicated a $31 \pm 3\,km^3$ loss in groundwater storage from 2006 to 2012 (Famiglietti et al. 2011; Scanlon et al. 2012). A recent study (Howitt et al. 2014) estimated that the 2014 drought resulted in an additional groundwater loss on the order of $6.3\,km^3$, and the depletion continues despite efforts to curb water use (Famiglietti 2014).

The present groundwater status in California's Central Valley is rooted in its history. For more than 50 years the Central Valley has been one of the most productive agricultural regions of the world, which is facilitated by sufficient supply of irrigation water (Bertoldi et al. 1991; Faunt 2009). Irrigation and agricultural activity have

* Utah Agricultural Experiment Station Publication Number 8720.

+ Supplemental information related to this paper is available at the Journals Online website: http://dx.doi.org/10.1175/JHM-D-15-0105.s1.

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DOI: 10.1175/JHM-D-15-0105.1

accounted for the vast majority of all water use: during the 1960s and 1970s, annual irrigation water was derived equally from groundwater and surface water, though in drought years the amount supplied by groundwater would increase (Bertoldi et al. 1991). In the early 1980s, the overall usage of irrigation water increased slightly, and an increased proportion came from surface water. According to USGS water use data for California, from the 1980s until 2010, the Central Valley began using less total water for irrigation, yet there has been an increase in the proportion taken from groundwater sources. The Central Valley has seen a rapid population growth from 5.7 million people in 2000 to 6.7 million people in 2010 (http://www.census.gov/2010census/), leading to increased household usage of water in addition to agricultural water use. In the meantime, groundwater storage in the Central Valley has declined by almost 60 million acre feet since the 1960s (Faunt 2009).

Climatic factors have affected groundwater in the Central Valley as well. The effects of global warming at the regional scale include a hotter and drier climate (Dai 2013) and earlier snowmelt (Westerling et al. 2006), both of which can aggravate drought conditions. A companion study that analyzed water cycle extremes in California (Yoon et al. 2015a,b) has projected that both intense drought and excessive flooding will increase by at least 50% toward the end of the twenty-first century, and such an increase is linked to strengthened impacts from the life cycle of El Niño–Southern Oscillation (ENSO) (Wang et al. 2015). Given the severe drought conditions in California, a pressing question posed is whether the state will experience continued shortfalls in groundwater in upcoming years. To better assess future water resources, this study investigated the linkage between groundwater and drought, and particularly the hypothesis that the recent and projected amplification of water cycle extremes in California (Yoon et al. 2015b) may exacerbate groundwater depletion. Using diagnostic approaches, this study represents a preliminary investigation of likely climatic factors in the drought–groundwater relationship.

2. Data and methods

a. Data

Depicting drought in the state of California can be complicated owing to its terrain and associated snow hydrology. The Palmer drought severity index (PDSI; Dai 2013) has been the most widely used metric for drought depiction and is the front-page indication of drought status in the U.S. Drought Portal (www.drought.gov). Here, we utilized the PDSI data produced by the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) with a 4-km resolution (http://prism.nacse.org/). However, the PDSI could be problematic in the western United States in that it does not account for time lags introduced by snow accumulation and, as a result, may handle California's snow cycle poorly. Thus, we adopted additional measures of drought by using the Climate Prediction Center (CPC) model-calculated monthly soil moisture water height equivalents (hereafter soil moisture) at 0.5° grid spacing (http://www.esrl.noaa.gov/psd/data/gridded/data.cpcsoil.html) and the Climatic Research Unit (CRU) Time-Series, version 3.21 (TS3.21), gridded precipitation and temperature data (http://www.cru.uea.ac.uk/data). All these gridded data were averaged in the Central Valley, defined as elevations lower than 1000 m (Fig. 1a).

For the estimation of groundwater storage, we utilized the level-3 GRACE data of monthly liquid water equivalent thickness (LWET) provided by NASA GRACE Tellus (http://grace.jpl.nasa.gov/; Landerer and Swenson 2012). The GRACE twin satellites detect gravity changes and use them to measure variations in water stored at all levels above and within the land surface; this measurement indicates terrestrial water storage change. The GRACE-derived LWET (hereafter LWET) was averaged within the Central Valley. Although the Central Valley has a smaller areal extent than the GRACE footprint, previous studies (Famiglietti et al. 2011; Scanlon et al. 2012; Anderson et al. 2015) have shown that GRACE-derived groundwater storage change is in agreement with the well data within the valley. We note that the LWET signal may not completely reflect groundwater since the signal leakage effect coming from proximity of the Sierra Mountains (i.e., snow, soil moisture, and surface water) was not removed.

Groundwater level measured by wells within the Central Valley was obtained from two sources: the U.S. Geological Survey (USGS; http://waterdata.usgs.gov/nwis) and the California Department of Water Resources (DWR; http://www.water.ca.gov/). We used 467 wells as indicated in Fig. 1a; these are wells that provide observations in any month during the September–December period with at least 15 years of data. The available data length of each well is plotted as horizontal lines in Fig. S1 of the supplemental material, and the numerous data gaps reflect the well-known problem that groundwater observations in the Central Valley are inhomogeneous and discontinuous (Kennedy 2014). To form long-term time series of groundwater level, one needs to combine these well data; to do so, groundwater level of each well was first standardized (within ±1) and then averaged across all wells to form a single time series. This procedure eliminates the difference and

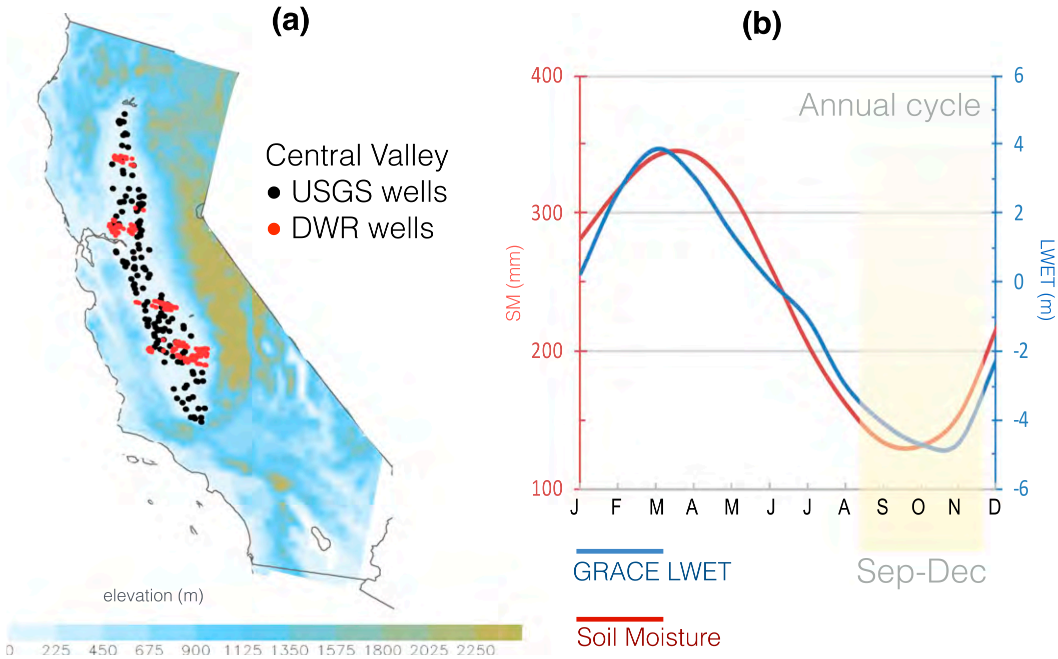

FIG. 1. (a) Topography of California that outlines the Central Valley (<300 m) overlaid with the 497 wells analyzed, obtained from USGS (black dots) and California DWR (red dots). (b) Long-term monthly distribution of LWET (blue) and soil moisture (red) averaged in the Central Valley, while the low season of September–December is highlighted.

locality of well levels. As shown in Fig. S1, we conducted a sensitivity test for different parts of the Central Valley: north, central, and south (discussed later). Groundwater level fluctuation is considered uniform throughout the valley despite the limited number of wells after the year 2000. Additional water use data referred to in the text were provided by the USGS (http://waterdata.usgs.gov/ca/nwis/water_use/).

b. *Methods*

To understand the cause and effect of the Central Valley's groundwater problem and to help visualize the temporal change and areal extent from which the problem is derived, we first used the Pearson correlation and cross correlation. Correlation is a simple and direct way to understand the relationship between two variables and associated change, while cross (lagged) correlation provides an effective measure to establish the similarity of two variables as a function of the time lag of one relative to the other. For the purpose of examining the time–frequency distribution of drought and groundwater, that is, how the variation changes over time, as well as further validation of correlation analysis, we conducted the wavelet power spectrum analysis following the derivation of Torrence and Compo (1998). The wavelet coefficients yield information about the correlation between the wavelet (spectral power) and the data array (at a particular data point). To verify lagged correlations, we utilized the wavelet transform coherence (WTC) for analyzing the coherence and phase lag between two time series as a function of both time and frequency. The WTC analysis is based on the continuous wavelet transform developed by Grinsted et al. (2004) for geophysical time series. Significance test was performed by using the Monte Carlo method (i.e., adding random noise to the two signals and repeating this 1000 times) to calculate the 95% confidence interval about the "true" phase difference.

3. Results

In the California Central Valley, groundwater undergoes a pronounced annual cycle that peaks in March and reaches minimum in November, as is displayed in Fig. 1b by the long-term LWET data. Recharge begins in November, at the start of the rainy season, and typically lasts until March. Soil moisture in the Central Valley exhibits an annual cycle similar to LWET (Fig. 1b). Based upon this annual cycle, the period of September–December appears to be the low season of groundwater level. Thus, we divided the year into three different seasons (January–April, May–August, and September–December) and computed the cross correlations between the PDSI and LWET averaged over the

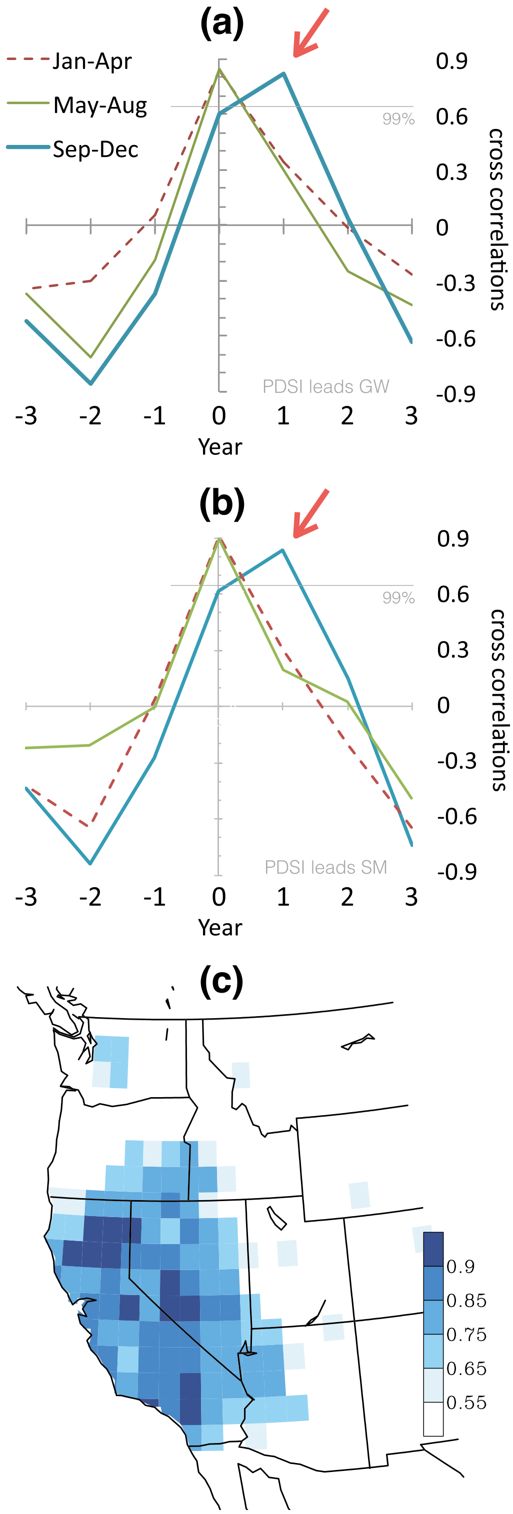

FIG. 2. (a) Cross correlations between PDSI and LWET over the Central Valley for each 4-month season as indicated in the legend. The gray line indicates the 99% confidence level; the red arrow indicates the significant lagged correlation in the September–December season. (b) As in (a), but for soil moisture and LWET. (c) Point-to-point correlations between the September–December PDSI and LWET in the following year. Only values that are above the 99% confidence level are plotted.

Central Valley during 2002–14. As shown in Fig. 2a, the September–December period is the only season whose correlations are significant both at the current year (year 0) and at a 1-yr lag (year +1), suggesting a prolonging effect of meteorological drought on groundwater. It could mean that groundwater decline in autumn is maintained over a 2-yr period that persists approximately one full year after drought has occurred (or seized). A similar pattern in the correlations is observed between soil moisture and LWET (Fig. 2b) as well as precipitation (not shown), which lends support to the prolonging effect of drought on groundwater depletion. We also computed the point-to-point correlation between the grid-scale PDSI (year 0) and LWET (year +1) to delineate the geographical distribution of this year +1 correlation, using the September–December data. As shown in Fig. 2c, significant correlations encompass the Central Valley and extend into Nevada, southeastern Oregon, and northwestern Arizona. This regional extent of year +1 correlations suggests that the occurrence of drought affecting the Central Valley is associated with a larger-scale climate pattern beyond the state of California.

Of further relevance, prior to the twenty-first century the 1-yr lag in the drought–groundwater correlation was not apparent: Fig. 3a presents evidence from wells in the Central Valley by computing correlations for a series of sliding, trailing 15-yr windows between PDSI (year 0) and groundwater level (year +1), based on September–December (hereafter "sliding correlations"). Actual time series of PDSI and groundwater level are displayed in Fig. 4a for visual inspection. The contemporaneous (year 0) correlations are rather stable and remain marginally significant throughout the analysis period, as expected. By comparison, the lagged (year +1) correlations increase drastically and become significant ($p < 0.01$) at the beginning of the twenty-first century. Prior to that, the year +1 correlations are insignificant, suggesting that the situation of protracted groundwater decline a full year after drought was not the case. A similar analysis using soil moisture (Fig. 3b) obtained the same conclusion, that the year +1 correlations have increased prominently since 2005. This strengthened effect of drought in prolonging groundwater depletion was previously undocumented. The cause of such a change in lagged correlations is manifold and we acknowledge that a lot of factors that are involved in water management could obscure the relationship between drought and groundwater; these are addressed in section 4.

We tested the significance for the difference in the sliding correlations by applying a bootstrapping scheme with 500 pairs of correlated white noise time series, following Gershunov et al. (2001); the test result

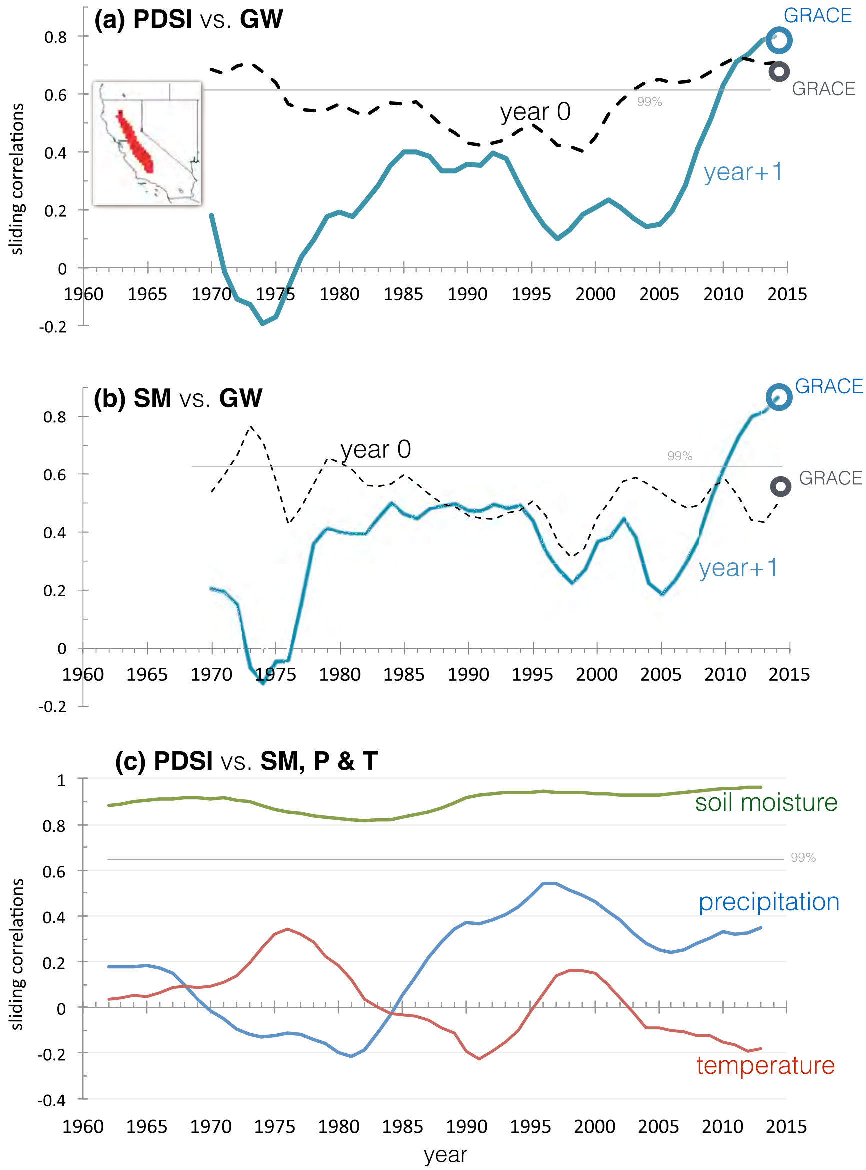

FIG. 3. (a) Sliding correlations between the Central Valley PDSI and the groundwater level (GW) in the following year (year +1; blue solid line) and in the same year (year 0; black dashed line), computed with a 15-yr running window (one sided). The LWET correlations with PDSI are indicated by thick circles for 2002–14. Gray horizontal lines indicate the 99% confidence level. (b) As in (a), but for soil moisture (SM) and GW. (c) Sliding correlations (no lag) between the PDSI and SM (green line), precipitation P (blue line), and surface air temperature T (red line) within the Central Valley using a centered, 15-yr running window.

indicates a significant post-2005 difference at $p < 0.01$. We also examined the sliding correlations using various window sizes from 10 to 20 years, and those too yielded consistent results (not shown). In terms of geographical difference, we computed these correlations from each subregion of the Central Valley as indicated in the supplemental material. The result as shown in Fig. S1 suggests that the correlations are not sensitive to the region we selected (though the southern Central Valley exhibits a lower year +1 correlation in recent years). Moreover, the LWET–PDSI correlations for the 2002–14 period (indicated by open circles in Fig. 3a) align with the well data analysis, and this agreement suggests that any potential bias that resulted from the signal leakage effect of GRACE within the Central Valley is minimal.

Since groundwater depletion in semiarid areas such as the Central Valley is largely controlled by soil moisture storage change (Rodell et al. 2007; Long et al. 2013), the

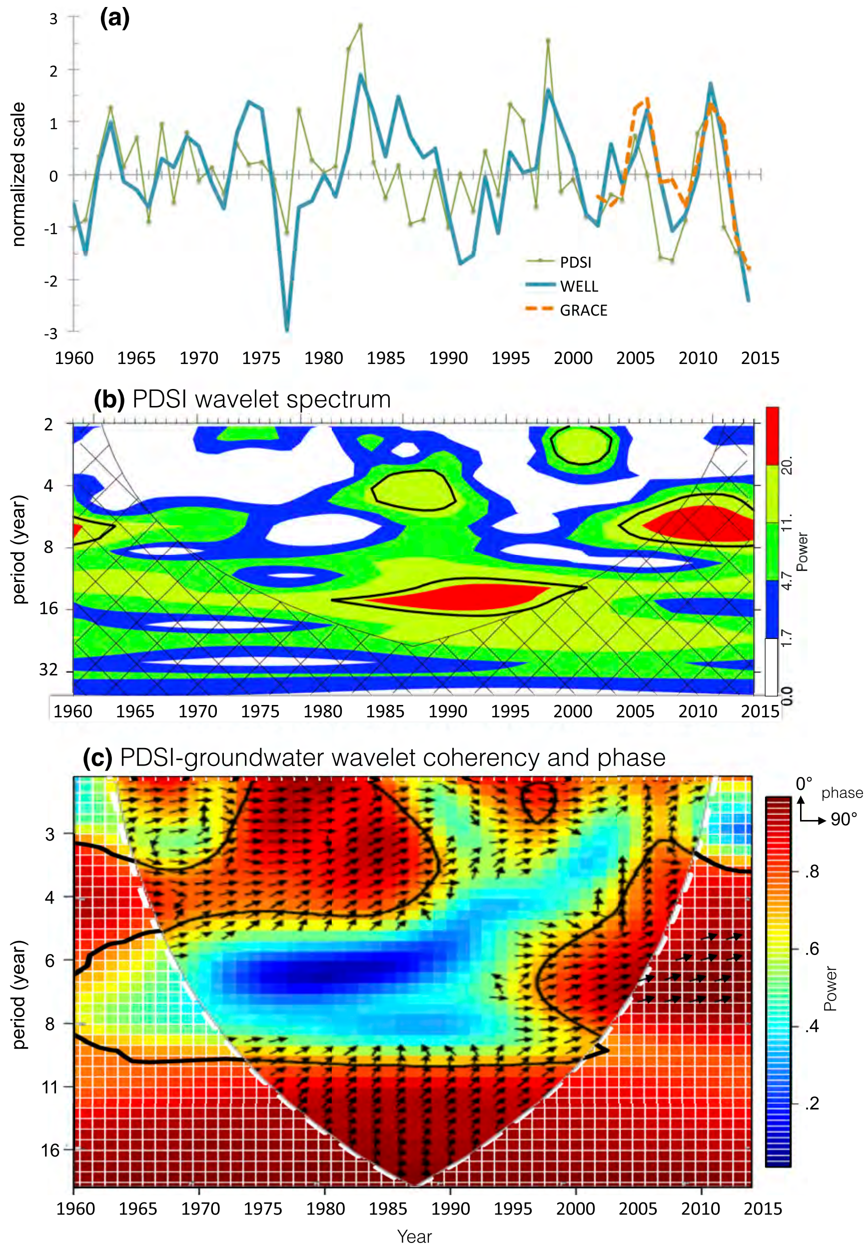

FIG. 4. (a) Time series of the September–December PDSI (green line), LWET (orange dashed line), and GW (blue line) from 1960 to 2014. (b) Wavelet spectrum of the PDSI using the Morlet parameter-6 approach, in which the contour levels are chosen so that 75%, 50%, 25%, and 5% of the wavelet power are above each level. (c) Wavelet coherency (shading) and phase (vectors) between the PDSI and GW. Vectors pointing to the right indicate a quarter phase. The cone of influence and the 95% confidence level based on red noise are hatched/contoured.

expectation is that groundwater storage, soil moisture, and drought occurrence would be highly correlated (Famiglietti et al. 2011; Castle et al. 2014). Figure 3c reflects such a process through the computation of sliding correlations between PDSI and soil moisture, precipitation, and surface air temperature within the Central Valley. The PDSI shows a weak association with precipitation and temperature, although the correlations with precipitation have increased after 1980 (yet insignificant). The PDSI's correlation with soil moisture has been significant and consistently high (~0.9) throughout the past 65 years. Therefore, it is possible that the prolonging effect of drought and low soil moisture on groundwater level has increased. This notion echoes recent observations (AghaKouchak et al. 2014a; Griffin and Anchukaitis 2014; Diffenbaugh et al. 2015) that long-term warming during the recent decades and the record high temperature in summer can aggravate drought severity through increased evapotranspiration (Anderson et al. 2015), which furthers the reduction in soil moisture. Enhanced high pressure anomaly over the West Coast that was linked to increased anthropogenic warming (Wang et al. 2014; Diffenbaugh et al. 2015) also contributes to the lengthening of dry/warm days, which helps increase evaporation from the soils.

To illustrate the history of drought variability experienced in the Central Valley, Fig. 4a shows the September–December PDSI alongside the groundwater well levels and LWET. The low-frequency variability in all these datasets is discernable. It appears that the tendency for any drought to last longer than 2 years has become more pronounced. The changing drought frequency was assessed using the wavelet spectral analysis (Torrence and Compo 1998) of the PDSI, and the result is shown in Fig. 4b. Since the late 1990s, spectral power within the 4–6-yr frequency undergoes considerable amplification. The effect of this amplified drought variation on groundwater was examined by computing the wavelet spectral coherency between PDSI and groundwater level using the formulation derived by Grinsted et al. (2004). As shown in Fig. 4c, significant coherency between the two variables in the 4–6-yr frequency appears after 1995 with a phase difference of (vector pointing toward) 75°; this phase difference amounts to a time lag of 1 year within a 4–6-yr ''cycle,'' lending support to the increased year +1 correlations presented in Fig. 3a.

Noteworthy is the 1980–95 period when the Central Valley experienced a lower-frequency climate fluctuation in the 10–16-yr time scale (Fig. 4b) in which the depletion of groundwater lags drought by certain years (Fig. 4a). Previous research has reported an energetic 10–20-yr (or quasi decadal) oscillation in the western United States, and its signal is especially pronounced in Northern California (Wang et al. 2009; St. George and Ault 2011). As is shown in Fig. 4c, the 50° phase difference within the significant 10–16-yr coherency indicates a time lag of about 2–3 years. Consequently, the prolonging effect of drought on groundwater depletion during this time period is not revealed as strongly from the year +1 correlations in Fig. 3a.

4. Discussion

What are the possible causes for the recent increase in the lagged correlations between the PDSI and groundwater level in the Central Valley? In terms of climatic factors, there is a tendency that drought conditions in California have become increasingly more intense and lasted longer (Cayan et al. 2010; MacDonald 2010; Diffenbaugh et al. 2015). Previous studies (Wang et al. 2009; Cayan et al. 2010; Seager and Vecchi 2010) have noted an intensification in the low-frequency drought variation across the western United States, echoing the result shown in Fig. 4. Recent studies (Wang et al. 2015; Yoon et al. 2015b) linked this intensified drought variation with strong ENSO events that modulate California's climate not only through the warm and cold phases but also their precursor patterns. Using large-member ensemble simulations, Yoon et al. (2015a) found a large increase specifically in the 4–6-yr spectral coherency shared by the El Niño–La Niña cycle and California's precipitation, vegetation index, and fire probability and attributed such a change to an increased association with the El Niño–La Niña teleconnections. To put these results into the context of this study, we adopted from Yoon et al. (2015a) the power spectrum of California's winter precipitation simulated by the Community Earth System Model, version 1 (CESM1), Large Ensemble Community Project, which is displayed in Fig. S2a. The result indicates a prominent increase in the variation of the 4–6-yr frequency. Likewise, Fig. S2b shows the spectral coherency of the precipitation with the ENSO cycle (represented by the Niño-3.4 index), and it too suggests a strengthened relationship in the same 4–6-yr frequency. This additional result is supportive of the 4–6-yr wavelet coherency between the PDSI and groundwater in the Central Valley observed in Fig. 4c, as well as their phase lag of 1 year.

In terms of local effects, the 2014 drought induced heat waves that resulted in the first half of the year being the hottest in 120 years of state record (James 2014); this subsequently exacerbated the drought situation and, according to the observations by Bertoldi et al. (1991) and Anderson et al. (2015), would prompt further withdrawal from the aquifer. Changes to surface water deliveries could very well affect the correlations discussed, yet there have been indications that they are not the leading cause for the increase in year +1 correlations. For instance, by focusing on the Colorado River basin, Famiglietti (2014) noted a disconnect between reservoir storage and groundwater level while stating that ''the steepest rate of groundwater storage decline (in the upper Basin in 2013) follows exceptional drought conditions in 2012 and record low Rocky Mountain snowpack.'' While it is expected that low snowpack affects surface water availability and thus tends to promote groundwater pumping, the notion in Famiglietti (2014) (alongside his Fig. 3) suggests that drought is the leading contributor to groundwater behavior, rather than changes in reservoir storage. If this idea is applied to California, it would imply that drought is the leading cause for the change in year +1 correlations since the 2000s rather than the change in reservoir storage. Meanwhile, it is also possible that existing water management practices in surface water resources, nonlocal water supplies, river flow control, reclamation, changes in usage, etc. could complicate the relationship between drought and groundwater level. Given that groundwater is unregulated and has been mined indiscriminately during this prolonged drought, some of the findings as presented here may be tempered.

In the context of climate change, since the CESM1 simulation of the changing association between ENSO cycle and California's precipitation as shown in Fig. S2 was derived from a higher representative concentration pathway (RCP8.5) of anthropogenic greenhouse gases, the amplification in the drought variation and the associated protraction of groundwater depletion is likely to continue. Further research is necessary to comprehensively understand the climate and hydrological linkages that manifest in the groundwater response to the changing frequencies of drought.

5. Conclusions

We present evidence that, since the beginning of the twenty-first century, groundwater levels in the Central Valley have tended to decline not only in response to drought conditions of the same year but also in the following year. In addition to the climatic factors outlined earlier, the reported long-term increase in groundwater withdrawal could play a role. Undeniably, the accelerated depletion in groundwater is linked to increased withdrawal (Famiglietti et al. 2011; Scanlon et al. 2012; Famiglietti 2014) and the drilling boom since 2014 is yet another compelling piece of evidence. However, quantifying the role of human withdrawal of groundwater is difficult because of the lack of reliable data. Performing land surface modeling with irrigation fluxes by utilizing GRACE groundwater storage estimate, as was recently done by Anderson et al. (2015), may offer a clue. Nonetheless, the present analysis for the Central Valley points to the fact that the effects of drought are becoming overarching and can be enduring. Despite changing water use habits, the water table continues to drop while drought becomes longer and more severe.

As of January 2016, an El Niño has fully developed and an alert was announced by the NOAA CPC (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/). This El Niño, if it persists through spring 2016 (as it is being predicted to), could enhance precipitation in California and bring some relief to the current drought conditions. However, the analysis presented here suggests that, even in the face of some drought recovery, groundwater depletion in the Central Valley will likely continue into late 2016, resulting in further reduction in groundwater level. The groundwater table in the Central Valley has been declining to such a degree that it requires a deeper understanding of the temporal dynamics of drought, their dependence on regional climate variability and change, and their implications for water demand and use in all forms.

Acknowledgments. Insightful comments offered by Dr. Andy Wood and two anonymous reviewers, as well as discussions with Matt Rodell, Hiroko Kato, and Calvin Poulsen, are highly appreciated. We are grateful to Laurel Rogers and Patricia Orlando of USGS for providing crucial water information. Data of GRACE Tellus is supported by NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) program available at http://grace.jpl.nasa.gov. CESM1 Large Ensemble Project (LEP) data are available at https://www2.cesm.ucar.edu/models/experiments/LENS. This research was supported by the Bureau of Reclamation Grant R13AC80039, NASA Grant NNX13AC37G, and the Utah Agricultural Experiment Station, Utah State University.

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EXHIBIT
7

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2014GL061055

Groundwater depletion during drought threatens future water security of the Colorado River Basin

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Key Points:
- Groundwater depletion in the Colorado River Basin is greater than we thought
- As GW disappears, the basin will struggle to supply water to the seven basin states
- It is time to bring groundwater under the water management umbrella

Supporting Information:
- Readme
- Figure S1
- Figure S2
- Figure S3
- Figure S4

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Citation:
Castle, S. L., B. F. Thomas, J. T. Reager, M. Rodell, S. C. Swenson, and J. S. Famiglietti (2014), Groundwater depletion during drought threatens future water security of the Colorado River Basin, *Geophys. Res. Lett.*, *41*, 5904–5911, doi:10.1002/2014GL061055.

Received 1 JUL 2014
Accepted 21 JUL 2014
Accepted article online 24 JUL 2014
Published online 29 AUG 2014

Abstract Streamflow of the Colorado River Basin is the most overallocated in the world. Recent assessment indicates that demand for this renewable resource will soon outstrip supply, suggesting that limited groundwater reserves will play an increasingly important role in meeting future water needs. Here we analyze 9 years (December 2004 to November 2013) of observations from the NASA Gravity Recovery and Climate Experiment mission and find that during this period of sustained drought, groundwater accounted for 50.1 km^3 of the total 64.8 km^3 of freshwater loss. The rapid rate of depletion of groundwater storage (-5.6 ± 0.4 km^3 yr^{-1}) far exceeded the rate of depletion of Lake Powell and Lake Mead. Results indicate that groundwater may comprise a far greater fraction of Basin water use than previously recognized, in particular during drought, and that its disappearance may threaten the long-term ability to meet future allocations to the seven Basin states.

1. Introduction

Over a decade, drought in the Colorado River Basin (Basin; Figure 1) has exposed the vulnerability [*Bureau of Reclamation*, 1975; *Barnett and Pierce*, 2008] of the most overallocated river system in the world [*Christensen et al.*, 2004]. Recently, the U.S. Bureau of Reclamation acknowledged the potential challenges [*Bureau of Reclamation*, 2012] to meeting future surface water allocations to the seven Basin states (Figure 1), noting that the contribution of local supplies, including groundwater withdrawals, will be required to offset anticipated shortages. While the need to exploit groundwater resources to meet Basin water demands has long been recognized [*Bureau of Reclamation*, 1975], withdrawals required to meet current demands remain undocumented and are uncertain in the future. In particular, water management under drought conditions focuses on surface water resources [*Basin Interim Guidelines*, 2007] without a regulatory framework to manage groundwater withdrawals outside of "river aquifer" systems [*Leake et al.*, 2013]. At question is the potential impact of solely managing surface water allocations and diversions in the Basin, without regard to groundwater loss, on meeting future water demands.

The ability to observe changes in water resources at large scales has been greatly facilitated by the deployment of recent Earth-observing satellites. One such satellite mission, the NASA Gravity Recovery and Climate Experiment (GRACE) [*Tapley et al.*, 2004], has measured the temporal variations in the Earth's gravity field since March 2002. These observations are now routinely applied to estimate the monthly changes in terrestrial or total land water storage (i.e., all of the snow, surface water, soil moisture, and groundwater) in regional areas that are 200,000 km^2 or larger [*Wahr et al.*, 2004] (Figure 2). Several studies have now demonstrated that GRACE observations, when combined with coincident data sets for snow water equivalent (SWE), surface water storage, and soil water content in a mass balance, can quantify changes in groundwater storage with sufficient accuracy [e.g., *Rodell et al.*, 2009; *Famiglietti et al.*, 2011] to influence regional water management decisions [*Famiglietti and Rodell*, 2013].

Our goal in this report is to identify changes in freshwater storage, including surface reservoir and groundwater storage, to assess the influence of conjunctive surface water and groundwater use on water availability in the Colorado River Basin during the recent drought. We evaluate the terrestrial water storage anomalies (TWSA) using GRACE observations during a 9 year period (December 2004 to November 2013) that begins 4 years into a prolonged drought in the southwestern United States, after water levels in Lake Powell

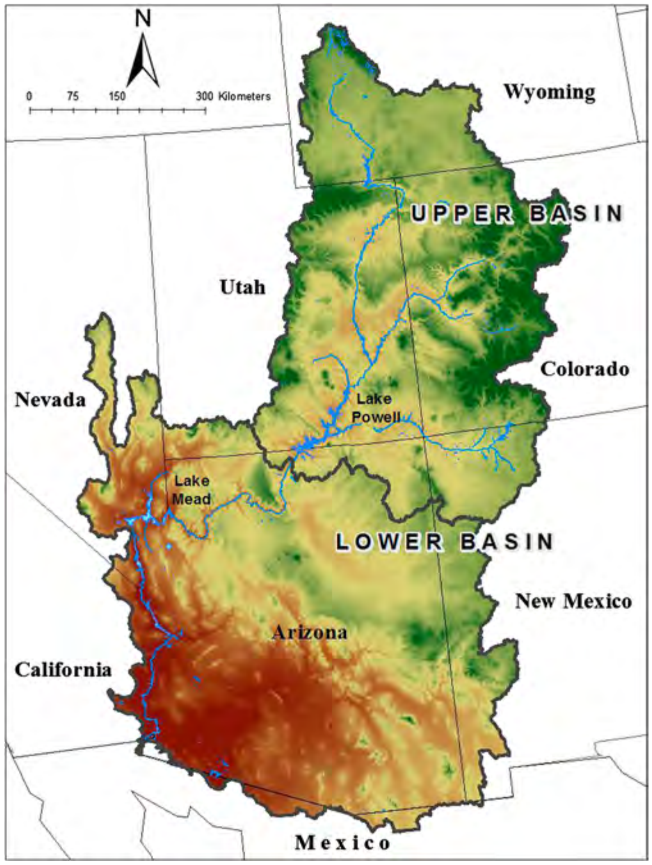

Figure 1. The Colorado River Basin of the western United States. The state and international boundaries are in light gray. The green and brown colors represent the high and low elevations, respectively [*McKay et al.*, 2012]. The upper Basin is that portion of the Basin upstream of Lake Powell. The lower Basin is the remainder of the basin downstream of Lake Powell. The basin outlines are in dark gray. The river, its main tributaries, and Lake Powell and Lake Mead are shown in blue.

and Lake Mead had declined precipitously [*Piechota et al.*, 2004] (see Methods section). In particular, we estimate the changes in groundwater storage during the 9 year drought period, when reservoir volumes were intensively managed to maintain hydropower production and to meet surface water allocations to the Basin states.

2. Methods

We used the Release 05 of the University of Texas Center for Space Research GRACE data [*Tapley et al.*, 2007] (ftp://podaac.jpl.nasa.gov/allData/grace/L2/CSR/RL05/). Average water storage changes for the Colorado River Basin were computed as anomalies of terrestrial water storage in equivalent water height (in millimeters, converted to cubic kilometers here using the area of the study basins) following *Swenson and Wahr* [2009] (Figure 2). Processing methods include filtering GRACE data to reduce noise [*Swenson and Wahr*, 2006] and later restoring the associated lost signal over a specific region by scaling the data correctively [*Velicogna and Wahr*, 2006]. This processing results in estimates of satellite measurement error and leakage error from out-of-basin signal, both of which are included in a Basin-specific time-invariant error estimate [*Wahr et al.*, 2006]. Figure 2 shows the Basin time series of terrestrial water storage changes from January 2003 to November 2013, nearly the complete available GRACE data record.

Because our focus here is on quantifying groundwater storage changes versus surface water storage changes during drought, we restrict our analyses to the 9 year period from December 2004 to November 2013. Prior to December 2004, the Basin had experienced four additional years of drought, effectively limiting surplus inflows that replenish Lake Powell and Lake Mead. This caused steep declines in reservoir storage prior to December 2004. Late 2004 also marked the beginning of a clear drought signal in the GRACE data, relative to its launch date in March 2002 (Figure 2).

To assess the accuracy of the GRACE data used here, we performed independent water budget analyses using regional precipitation (P) data from the PRISM system [*Daly et al.*, 2008] (http://prism.oregonstate.edu/recent/), satellite-based evapotranspiration (ET) from Moderate Resolution Imaging Spectroradiometer (MODIS) [*Tang et al.*, 2009], and the U.S. Bureau of Reclamation dam releases (Q) (usbr.gov; accessed December 2013) on the Colorado River. Uncertainty in the water balance estimate [*Rodell et al.*, 2004a, 2004b] was calculated assuming relative errors of 15% for P [*Jeton et al.*, 2005] and 5% in Q [*Rodell et al.*, 2004b]. A 15% bias on the daily ET was determined by *Tang et al.* [2009]; we assume the relative error increases to 25% on a monthly time scale. We computed the monthly storage changes, dS/dt, as $P - ET - Q$, and compared them to dS/dt derived from the GRACE terrestrial water storage anomalies using a discrete backward difference. Results illustrate a good agreement between dS/dt derived from the water budget and that

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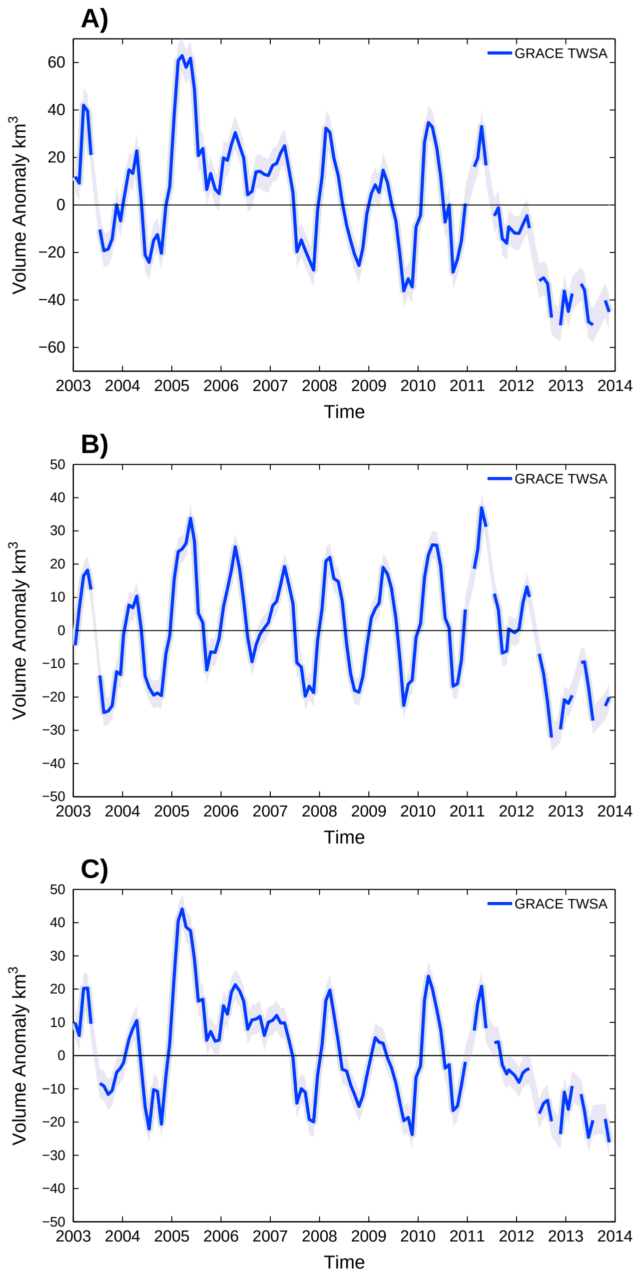

Figure 2. Monthly anomalies (deviations from the mean of the study period) of the total water storage (TWSA) for (a) the entire Basin, (b) the upper Basin, and (c) the lower Basin, from January 2003 to November 2013 (i.e., the full GRACE RL05 record available at writing). The three TWSA estimates were calculated independently using basin-specific scaling. The anomaly errors are shown in light blue shading. There are inconsecutive gaps in the GRACE data record, increasing in number toward the end of the time period due to recent declines in satellite power supply. Subsequent analyses focus on the period of prolonged drought extending from December 2004 to November 2013.

observed by the GRACE, for the entire Basin, and the upper and lower Basins (Figure S1 in the supporting information). Our comparisons were limited to March 2005 to March 2010 owing to the availability of *ET* estimates. Numerous additional studies have shown strong correspondence between GRACE water storage changes, hydrologic fluxes, and observations [see, e.g., *Swenson et al.*, 2006; *Famiglietti et al.*, 2011].

Accessible water storage changes (the combination of surface reservoir and groundwater storage changes) in the Basin are quantified using a water mass balance approach. Studies [e.g., *Rodell and Famiglietti*, 2002; *Rodell et al.*, 2009; *Famiglietti et al.*, 2011; *Scanlon et al.*, 2012] have shown that GRACE-observed water storage changes, in combination with additional data sets, can be used to isolate individual components of the terrestrial water balance. We assume that the total water storage in a region is composed of soil moisture (SM), snow water equivalent (SWE), surface water (SW), and groundwater (GW):

$$\mathrm{TWS}_t = \mathrm{SM}_t + \mathrm{SWE}_t + \mathrm{SW}_t + \mathrm{GW}_t, \quad (1)$$

where the subscript *t* indicates a function of time, and changes in these components balance in their sum. We apply GRACE observations of variations from the long-term mean of this total with estimates of soil moisture and SWE to quantify changes in accessible water. We simplify equation (1) by defining accessible water as the sum of groundwater and surface water storage:

$$\Delta\mathrm{AW}_t = \mathrm{TWSA}_t - \Delta\mathrm{SWE}_t - \Delta\mathrm{SM}_t, \quad (2)$$

where Δ indicates a variation from the time mean in an individual variable, and TWSA is the terrestrial water storage anomaly.

Soil moisture anomalies in equation (2) were estimated from the NASA Global Land Data Assimilation System (GLDAS) [*Rodell et al.*, 2004a] (http://disc.sci.gsfc.nasa.gov/) due to the lack of observational soil moisture data on large scales and for consistency with the previous studies [*Rodell et al.*, 2009; *Famiglietti et al.*, 2011]. We average the results of three land surface models from GLDAS (Variable Infiltration Capacity [*Liang et al.*, 1994], Noah [*Chen et al.*, 1996], and Community Land Model 2 [*Dai et al.*, 2003]) and apply the mean monthly standard deviation as an error estimate based on model structural biases (Figure S2 in the supporting information).

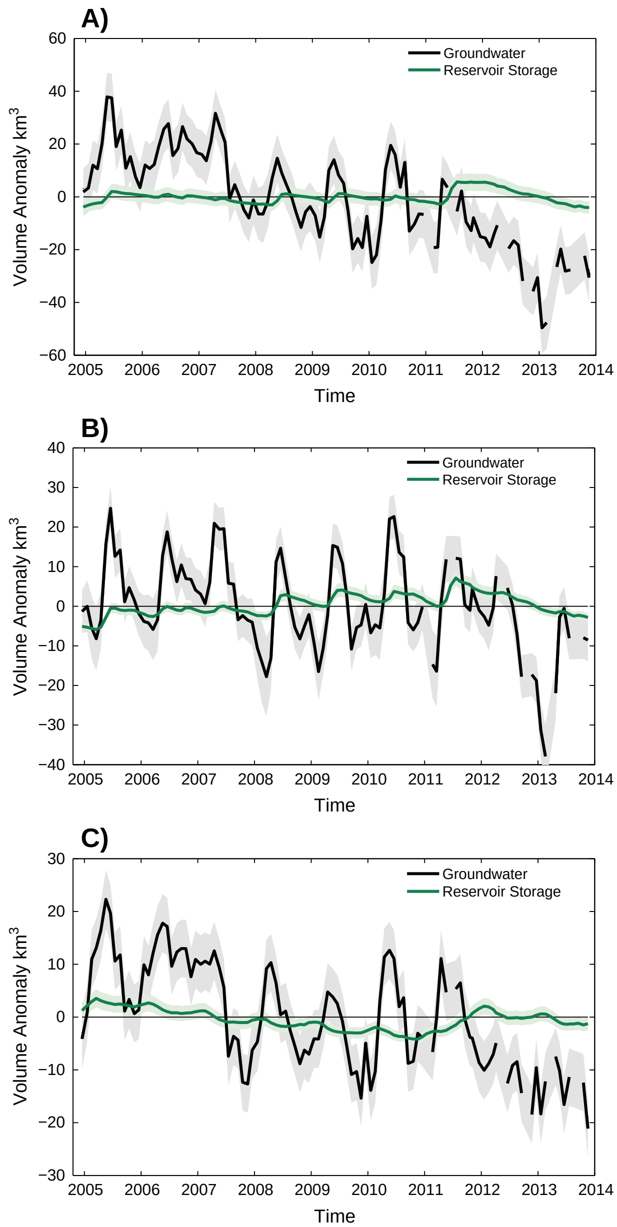

Figure 3. Monthly anomalies (km^3) of groundwater storage (black) and of surface reservoir storage (green) for (a) the entire Basin (trend: $-5.6 \pm 0.4\ km^3\ yr^{-1}$) and Lake Powell and Lake Mead combined (trend: $-0.9 \pm 0.6\ km^3\ yr^{-1}$), (b) the upper Basin (trend: $-1.7 \pm 0.4\ km^3\ yr^{-1}$) and Lake Powell (trend: $-0.6 \pm 0.6\ km^3\ yr^{-1}$), and (c) the lower Basin (trend: $-2.6 \pm 0.3\ km^3\ yr^{-1}$) and Lake Mead (trend: $-0.1 \pm 0.6\ km^3\ yr^{-1}$), from December 2004 to November 2013. The anomaly errors are shown in light gray shading for groundwater storage and in light green shading for reservoir storage. All trends are summarized in Table 1.

Data obtained from the Snow Data Assimilation System (SNODAS) [*National Operational Hydrologic Remote Sensing Center*, 2004] (http://nsidc.org/data/polaris/) were used for SWE in equation (2) (Figure S2 in the supporting information). SNODAS is the only gridded observation-based SWE product that assimilates ground, airborne, and satellite snow observations into its model structure and consequently has been used to represent SWE in other regional hydrologic studies [*Famiglietti et al.*, 2011; *Barlage et al.*, 2010]. Previous studies documented error of approximately 11% between SNODAS and snowpit observations in the Rocky Mountains [*Rutter et al.*, 2008] and 15% error for basin-wide analysis [*Famiglietti et al.*, 2011]. For this study, we assume 20% error due to the topographic and terrain heterogeneity throughout the Basin [*U.S. Geological Survey*, 2004].

We further separated the components of accessible water (Figure S3 in the supporting information) into surface water reservoir storage and groundwater storage (Figure 3). Reported reservoir storage time series from Lake Powell and Lake Mead were obtained from the U.S. Bureau of Reclamation [usbr.gov; accessed December 2013]. We assume that Lake Powell and Lake Mead account for the majority of the observed surface water change as they comprise approximately 4 times the annual flow of the river and make up 85% of surface water in the Basin [*Rajagopalan et al.*, 2009]. The U.S. Geological Survey (USGS) errors for hydrologic measurements ranging from "excellent (5%)" to "fair (15%)" [*Sauer and Meyer*, 1992] were used to provide error estimates for surface water reservoir storage. A two sample *t* test could not reject the null hypothesis that sample means were different using the USGS ranges in error, and throughout the rest of the analysis, we used a 10% error estimate for the surface water reservoir storage time series.

We rearranged equation (1) to isolate the contribution of groundwater storage changes (Figure 3) to changes in the total water storage (Figure 2). We used the reservoir storage changes in Lake Mead and Lake Powell with soil moisture and snow water equivalent data as described above:

$$\Delta GW_t = TWSA_t - \Delta SWE_t - \Delta SM_t - \Delta SW_t, \tag{3}$$

where ΔSW_t indicates the surface water anomaly from the reservoirs (Lake Powell and Lake Mead combined for the entire Basin: Lake Powell for the upper Basin and Lake Mead for the lower Basin). Equation (3) was

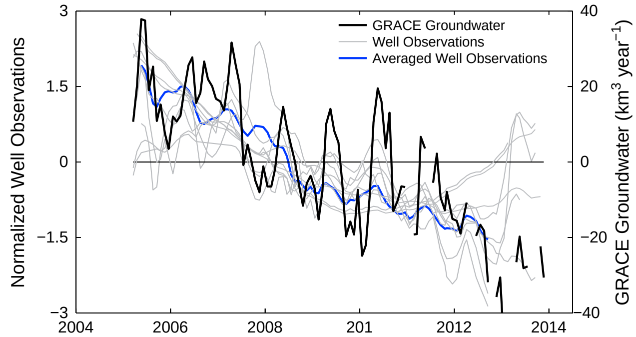

Figure 4. Entire Basin comparison between the GRACE groundwater storage anomalies (black line) in km^3 and the monthly USGS well observations. Because specific yield information is not available for all wells, we normalize each well time series by its standard deviation and then average (in blue). Selected well observations were only available from March 2005 to October 2012; thus, we calculated the average over this time period.

solved each month, and errors in the groundwater storage were estimated by propagating the errors of TWSA, SM, SWE, and SW, following *Rodell et al.* [2004b].

We compared our GRACE-based estimates of groundwater storage changes to groundwater level observations at 74 monitoring wells located throughout the Basin. These data were obtained from the USGS [*USGS Groundwater Climate Response Network*, 2014] and from the Arizona Department of Water Resources (ADWR; https://gisweb.azwater.gov/waterresourcedata/GWSI.aspx, accessed May 2014). The selection of wells for comparison was limited to the locations with observations that were concurrent with GRACE. Of these, 7 USGS and 65 ADWR were located in the lower Basin, and 2 USGS monitoring wells were identified in the upper Basin. GRACE-derived groundwater estimates generally capture the observed behavior well (see Results section and Figure 4).

The trends reported in the text and summarized in Table 1 were estimated employing a method that accounts for residual serial correlation and time series error, and subbasin trends may not sum linearly [*Johnston and DiNardo*, 1997]. We identified several significant trends over the entire 108 month time period studied, and in shorter time periods, from December 2004 to January 2010 and from February 2010 to November 2013 (Table 1).

Table 1. Trends in Water Budget Components Were Calculated Employing a Method Which Adjusts a Linear Model for Residual Serial Correlation and Time Series Error [*Johnston and DiNardo*, 1997][a]
Trends in Terrestrial Water in km^3/yr

Time	Component	Entire Colorado River Basin (CRB)	Upper CRB	Lower CRB
Entire time period	TWSA	**−7.18 ± 0.75**	**−2.34 ± 0.59**	**−3.90 ± 0.47**
December 2004 to November 2013	SWE	0.00 ± 0	0.00 ± 0	0.00 ± 0
	SM	−1.29 ± 1.8	−0.861 ± 0.85	**−0.905 ± 0.24**
	Reservoirs	−0.865 ± 0.60	−0.638 ± 0.63	−0.057 ± 0.63
	GW	**−5.56 ± 0.44**	**−1.66 ± 0.40**	**−2.63 ± 0.30**
	AW	**−5.40 ± 0.47**	**−1.13 ± 0.44**	**−3.02 ± 0.30**
Time				
Piecewise analysis 1	TWSA	**−10.6 ± 1.4**	**−3.41 ± 1.1**	**−7.49 ± 0.90**
December 2004–January 2010	SWE	0.00 ± 0	0.00 ± 0	0.00 ± 0
	SM	−2.67 ± 4.2	−1.74 ± 1.9	−1.45 ± 2.2
	Reservoirs	−0.428 ± 0.34	**1.31 ± 0.13**	**−1.20 ± 0.05**
	GW	**−6.23 ± 0.91**	**−1.91 ± 0.80**	**−4.06 ± 0.60**
	AW	**−6.29 ± 0.96**	−1.37 ± 2.2	**−5.27 ± 0.62**
Time				
Piecewise analysis 2	TWSA	**−19.2 ± 2.1**	**−11.5 ± 2.0**	**−9.14 ± 1.3**
February 2010 to November 2013	SWE	0.00 ± 0	0.00 ± 0	0.00 ± 0
	SM	**−6.82 ± 1.2**	**−2.88 ± 0.76**	**−3.64 ± 0.62**
	Reservoirs	−8.42 ± 4.7	**−3.22 ± 1.2**	−0.085 ± 2.0
	GW	**−10.9 ± 1.5**	**−6.10 ± 1.5**	**−5.83 ± 0.89**
	AW	**−11.2 ± 1.6**	**−7.48 ± 1.6**	**−4.85 ± 0.90**

[a]The approach identified several significant trends (shown in bold) in accessible water (AW) in the Basin over the entire time period from December 2004 to November 2013 and a piecewise trend analysis conducted from December 2004 to January 2010 and from February 2010 to November 2013. The Basin TWSA estimates are calculated independently, and there is no assumption that subbasin trends will sum linearly.

3. Results

We find that during the 108 month study period, the entire Colorado River Basin lost a total of 64.8 km^3 of freshwater (-7.2 ± 0.8 km^3 yr^{-1}, where ± represents the standard error of the slope coefficient) (Figure 2a) with a more severe rate of loss since February 2010 (-19.2 ± 2.1 km^3 yr^{-1}). The upper Basin (Figure 1) lost 21.6 km^3 of water during the entire study period, with more severe loss rates after February 2010 (-11.5 ± 2.0 km^3 yr^{-1}) (Figure 2b). Study period losses in the lower Basin of 34.7 km^3 were greater than in the upper Basin and declined at a faster rate (-3.9 ± 0.5 km^3 yr^{-1}) (Figure 2c). All trends are listed in Table 1. As described in the Methods section, we compared our GRACE-derived water storage estimates to independent water balances for the entire, upper, and lower Basins with good agreement (Figure S1 in the supporting information). This comparison lends additional confidence to the results reported here.

Further analysis of trends in groundwater storage (Figure S4 in the supporting information) revealed two distinct phases of depletion prior to and following 2009–2010. From December 2004 to January 2010, groundwater storage declined more rapidly in the lower Basin (-4.1 ± 0.6 km^3 yr^{-1}) compared to the upper Basin (-1.9 ± 0.8 km^3 yr^{-1}). Groundwater losses from February 2010 to November 2013 were found to be even greater in the upper (-6.1 ± 1.5 km^3 yr^{-1}) and lower Basins (-5.8 ± 0.9 km^3 yr^{-1}).

A brief recovery in groundwater storage is apparent from June 2009 to March 2010, when moderately wetter conditions provided a combination of potential groundwater recharge and temporarily alleviated the need to augment surface water supplies. The steepest rate of groundwater storage decline (in the upper Basin in 2013) follows exceptional drought conditions in 2012 and record low Rocky Mountain snowpack (U.S. Drought Monitor, 2012; see Figure S2 in the supporting information). Such behaviors highlight the close connection between surface water availability and groundwater use [*Famiglietti et al.*, 2011].

We find that water losses throughout the Basin are dominated by the depletion of groundwater storage (Figure 3). Renewable surface water storage in Lake Powell and Lake Mead showed no significant trends during the 108 month study period, more recent declines (since 2011) and currently low (<50% of capacity) storage levels notwithstanding. Groundwater storage changes however accounted for the bulk (Table 1) of the freshwater losses in the entire Basin (50.1 km^3 and -5.6 ± 0.4 km^3 yr^{-1}), the majority of which occurred in the lower Basin (Figure 3c). As mentioned in the Methods section, we examined the USGS and ADWR monitoring wells in the Basin during the study period. The observed behavior in these wells showed a good agreement with our GRACE-based estimates. Figure 4 shows the comparisons for the USGS wells. A Sen's slope trend comparison to the ADWR wells showed that measured groundwater table changes closely matched our GRACE-based estimates. These comparisons help confirm the groundwater depletion rates reported here.

4. Discussion

Drought in the Basin has effectively limited the surplus inflows that replenish Lake Powell and Lake Mead since the beginning of the 9 year study period, while active surface water management has prevented further declines in reservoir levels. Consequently, reservoirs show insignificant trends in storage levels (-0.9 ± 0.6 km^3 yr^{-1}), while groundwater has been significantly depleted (-5.6 ± 0.4 km^3 yr^{-1}). The vast difference may well be attributed to the regulatory framework already in place to manage surface waters, and to the general need for more active and enforceable groundwater management throughout the Basin, in particular, during drought.

The large, net negative change in groundwater storage is a clear indication that groundwater withdrawals are not balanced by recharge and must be greater than the observed depletion rate. The additional loss of 5.6 km^3 yr^{-1} of groundwater, relative to the annual Basin surface water allocations of 18 km^3 yr^{-1}, indicates further that the Basin water supply was overallocated by at least 30% during the study period. Thus, we observe that groundwater is already being used to fill the gap between Basin demands and the annual renewable surface water supply.

Groundwater is typically used to augment sparse surface water supplies in the arid, lower Basin, and across the entire Basin during drought [*Hutson et al.*, 2004; *Kenny et al.*, 2009]. More generally, water managers around the world rely on groundwater to mitigate the impacts of drought on water supply [*Leblanc et al.*, 2009; *Famiglietti et al.*, 2011; *Famiglietti and Rodell*, 2013; *Taylor et al.*, 2013]. Groundwater represents the largest supply of water for irrigation within the Basin [*Hutson et al.*, 2004; *Kenny et al.*, 2009], while irrigated acreage in the Basin has increased during our study period [*Ward and Pulido-Velazquez*, 2008; *Cohen et al.*, 2013]. Furthermore, prolonged drought across the southwestern U.S. has resulted in overreliance on groundwater to minimize impacts on public water supply [*Famiglietti and Rodell*, 2013]. Long-term observations of groundwater depletion in the lower Basin (e.g., in Arizona—despite groundwater replenishment activities regulated under the 1980 Groundwater Code—and in Las Vegas [*Konikow*, 2013]) underscore that this strategic reserve is largely unrecoverable by natural means and that the overall stock of available freshwater in the Basin is in decline.

Future water management scenarios that account for both population growth and climate change also point to the inability of reservoir storage alone to meet the Basin allocations [*Barnett and Pierce*, 2008; *Bureau of Reclamation*, 2012]. These scenarios indicate that additional stresses will be placed upon the groundwater system, beyond those described here, to meet future Basin water demands. We believe that the combination of reduced surface water availability resulting from decreasing future snowpack [*Barnett et al.*, 2008] and groundwater depletion poses a significant threat to the long-term water security of the region. As groundwater supplies reach their limits, the ability to supply freshwater during drought, or to fill the predicted, increasing gap between supply and demand [*Bureau of Reclamation*, 2012], will be severely constrained.

The challenge to policy makers and water managers in the Colorado River Basin is to reliably meet freshwater demand under these dynamic conditions. Our work suggests that a conjunctive surface water and groundwater management plan is essential for sustainable water management in the Basin. Despite commendable efforts to craft solutions to meet required surface water allocations [*Bureau of Reclamation*, 2012], consideration of the ability of groundwater withdrawals to meet current and future demands remains dormant. We hope that the heightened awareness of the rates of the Basin groundwater depletion highlighted here will foster urgent discussion on conjunctive management solutions required to ensure a sustainable water future for the Colorado River Basin and for the western United States.

Acknowledgments
This research was funded by grants from the NASA GRACE Science Team and from the University of California Office of the President, Multicampus Research Programs and Initiatives. Jason Christensen of the U.S. Bureau of Reclamation provided the reservoir capacities and dam releases. We thank Q. Tang of the University of Washington for the use of the MODIS ET data and Min-Hui Lo of the National Taiwan University for the assistance with the GRACE validation. Access to all data sets used in this study is available through the links provided in the main text. Authors J.T. Reager and J.S. Famiglietti conducted some of this research at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

The Editor thanks Sandra Postel and an anonymous reviewer for their assistance in evaluating this paper.

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EXHIBIT
8

Impact of Renewable Energy Sources on Birds of Prey

Chapter · July 2018

DOI: 10.1007/978-3-319-73745-4_13

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Birds of Prey

Biology and conservation in the XXI century

Springer

Contents

Chapter 13
Impact of Renewable Energy Sources on Birds of Prey

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Introduction

Renewable energy, defined as energy generated from natural processes that are replenished over time (Johnson and Stephens 2011), is increasingly important in global energy portfolios. This chapter begins by reviewing reasons for shifting from fossil fuels to renewable energy, including reasons which have nothing to do with environmental concerns but are nevertheless driving advances in the renewable sector. The chapter then focuses on birds of prey, describing actual and potential direct and indirect mortality, habitat loss, avoidance, and displacement resulting from the development and operation of renewable energy facilities. The chapter considers renewable energy facilities themselves, including wind, biofuel, solar, hydro, geothermal, and oceanic energy sources. Transmission connections linking renewable facilities to the existing electric transmission grid are considered, as are potential offsite impacts where the materials used to construct renewable infrastructure are mined and manufactured. The chapter closes with a discussion of mitigation strategies designed to reduce or compensate for negative impacts for birds of prey and a discussion of potential benefits of renewable energy facilities for birds of prey. The latter are important to understand when evaluating the overall balance of costs and benefits of renewable energies on birds of prey.

Knowledge of the connections between global conflicts and international dependencies on fossil fuels is important in understanding how macroeconomic forces independent of environmental concerns drive the advancement of renewable energy technologies. Because "green" initiatives may not in fact be grounded in environmental concerns, but be grounded instead in economics and national interests, potential negative environmental impacts of renewables and their high initial investment costs may carry little weight in the overall discussion, a paradox not readily apparent without consideration of the context of global competition over traditional energy reserves.

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J. H. Sarasola et al. (eds.), *Birds of Prey*,
https://doi.org/10.1007/978-3-319-73745-4_13

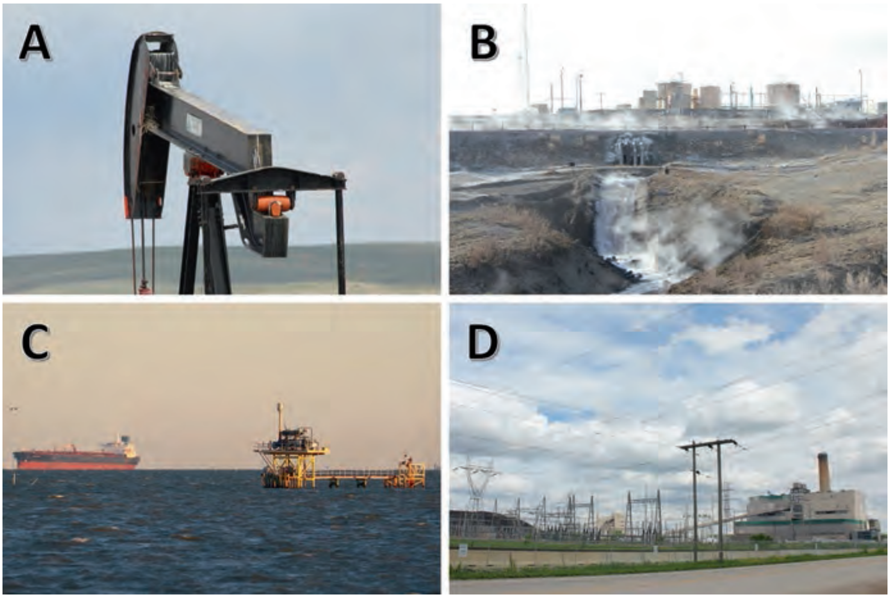

Fig. 13.1 (**a**) A pump designed to extract liquid and gas fossil fuels from terrestrial deposits; note great horned owl (*Bubo virginianus*) nest and whitewash. (**b**) Collection facility for traditional liquid and gas fossil fuels from terrestrial deposits. (**c**) Transport (left) and collection (right) of traditional fossil fuels, (**d**) Traditional coal-burning electricity generation station

Fossil fuels have been the primary energy source for developing and developed nations since the Industrial Revolution of the early 1800s when coal began to be used to power steam-driven machines and energy-intensive metallurgic and chemical processes. Emissions from these machines and processes were recognized almost immediately as harmful, triggering early environmental responses to protect urban air and water. From the late 1800s through the early twenty-first century, fossil fuels remained the primary solution to global energy needs as petroleum and natural gas products made the storage and use of chemical energy more efficient and economical (Fig. 13.1).

The resulting dependence of national and international economies on fossil fuels has created two fundamental problems. The first is a globally ubiquitous reliance on fossil fuels often derived from outside national boundaries. This reliance can place less developed nations with large reserves at the center of conflicts for control of those reserves and can place more developed nations without large reserves at the mercy of nations with reserves. Shifting energy sources from fossil fuels to renewables offers nations the ability to achieve energy independence.

The second fundamental problem created by the global reliance on fossil fuels is the impact of combustion products on the global climate. Greenhouse gases released during combustion of fossil fuels are contributing to global climate changes. Shifting energy sources from fossil fuels to renewables offers nations the ability to achieve energy independence and offers potential environmental benefits. These benefits are not without their own potential costs however, and it is those potential costs, as exerted on birds of prey populations, that are discussed here.

Effects at Renewable Facilities

Potential effects to birds of prey at renewable facilities include direct mortality and indirect effects resulting from habitat loss, avoidance, and displacement. Direct mortality is defined as death occurring as an immediate consequence of an interaction between a bird of prey and a component of renewable infrastructure. For example, a golden eagle (*Aquila chrysaetos*) killed when struck by a rotating wind turbine blade or killed when colliding with the suspended high-voltage wires of a transmission power line connecting a renewable facility to the electric grid. Habitat loss is defined as occurring when the landscape occupied by birds of prey is converted to non-habitat, for example, the displacement of prey species resulting from conversion of hunting habitat to a mirror field for a solar plant or the removal of a nest tree when creating an agricultural monoculture for biofuel production. Avoidance and displacement are similar processes occurring at different scales. Both occur when habitat persists, but is no longer used. Avoidance is defined as a shift in use of specific portions of a renewable facility, not the entire site (Band et al. 2007). Displacement occurs when an entire site is abandoned (Band et al. 2007).

These effects rarely occur in isolation but are instead likely additive, co-occurring with one another and with other anthropogenic and natural agents of mortality. Additive effects can be problematic, even at low rates, because most birds of prey are k-selected species with relatively little annual reproduction and breeding often delayed during multiple years of maturation. Population persistence for many bird of prey species requires individual breeding adults to produce young over an entire lifetime. Mortality of breeding adults can have substantial effects on the population (Bellebaum et al. 2013). For example, at some sites, griffon vultures (*Gyps fulvu*s) and red kites (*Milvus milvus*) cannot maintain stable local populations with additive mortality from wind farms (Carrete et al. 2009; Bellebaum et al. 2013).

Wind Resource Areas

Direct effects of wind energy facilities (Fig. 13.2) on birds of prey involve mortality occurring when rotating turbine blades strike birds in flight. Impacts are largely species-specific. Directly affected species are characterized by low-altitude flight when gliding on local winds and on thermal and orographic lifts (Katzner et al. 2012; de Lucas et al. 2008). Because wind turbines are designed and specifically placed to harvest the kinetic energy in some of these same winds, low-altitude flight behaviors largely dictate risk by placing birds of prey and rotating turbine blades

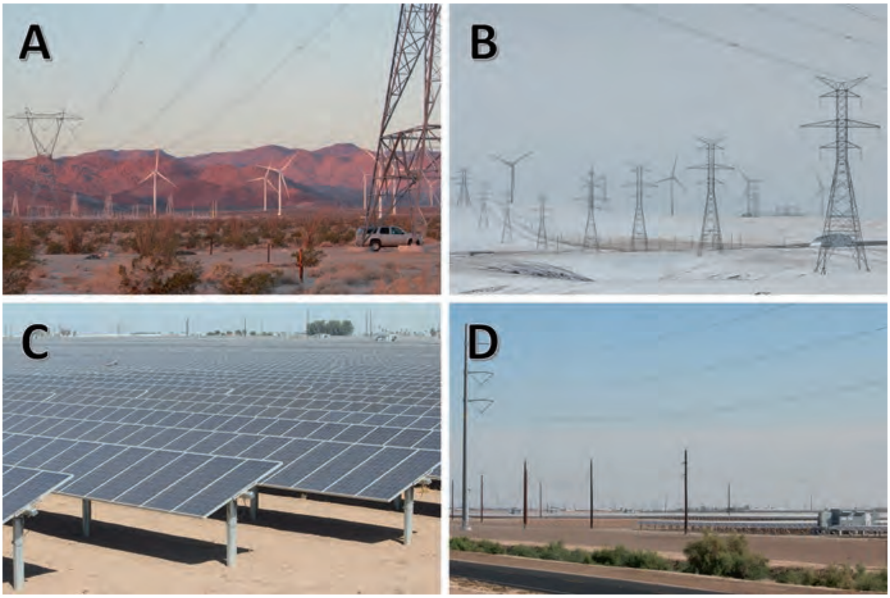

Fig. 13.2 (**a**) A wind resource area in desert habitat; note substation under construction in the background will provide a connection from the wind resource facility to the existing transmission power line network. (**b**) A wind resource area above agricultural fields, potentially facilitating both wind energy and biofuel production. (**c**) Close view of a solar field illustrating the bare and leveled earth (non-habitat) typical of such facilities. (**d**) Wide view of a solar field, illustrating fencing and bare earth designed to limit attractiveness as habitat and illustrating associated distribution and transmission lines

together in the same airspace. Hunting in these airspaces has been hypothesized to hinder the ability of a bird of prey to recognize turbines as a flight hazard (Orloff and Flannery 1992; Smallwood et al. 2009), so species habituated to hunting within wind resource areas can be at higher risk of collision. Collision risk can also increase along flight corridors where large numbers of migrating birds of prey funnel along narrow ridges and coastlines supporting wind energy facilities (Barrios and Rodriguez 2004; Katzner et al. 2012; de Lucas et al. 2012) or where communal roosts occur near wind resource areas (Carrete et al. 2012). Intraspecific and interspecific interactions during flight also increase risk for collision because birds of prey can be distracted and less likely to recognize flight hazards (Dahl et al. 2013; Smallwood et al. 2009).

Though at least 34 bird of prey species have been documented in collisions with wind turbines, population-level impacts from direct effects are unknown for most species (Beston et al. 2016); only griffon vultures (Carrete et al. 2009), red kites (Bellebaum et al. 2013) and golden eagles (USFWS 2013) are currently known to be at risk of population-level effects from these collisions.

Species-specific behaviors also drive indirect effects of wind resource areas. Species avoiding or displaced by wind resource areas tend not to be affected by direct mortality but may abandon breeding territories (Dahl et al. 2013), shift local space use (Walker et al. 2005), or decrease in local abundance (Garvin et al. 2011; de Lucas et al. 2004). Some species show avoidance behaviors for individual turbine structures by adjusting flight paths to fly between or around turbines (Cabrera-Cruz and Villegas-Patraca 2016; Hull and Muir 2013; de Lucas et al. 2004) or adjust altitude to fly over turbines in their path (Johnston et al. 2014; de Lucas et al. 2004). There is limited evidence of net population loss in birds of prey from avoidance or displacement attributable to wind resource areas, but effects could be important for threatened species when considered with direct effects (Martínez et al. 2010).

Biofuels

Biofuels primarily describe energy resources developed from agriculture and most often describe production by industrial farms focused on extracting the greatest possible crop yields per acre. Yields are maximized by eliminating as many non-producing inclusions as possible and by promoting maximum growth through regular inputs of synthetic chemicals. Eliminating inclusions requires conversion of potential nest groves and bird of prey hunting habitat to cropland. Chemical inputs regularly consist of fertilizers to maximize crop yields, and pesticides, rodenticides, and herbicides, to protect monoculture crops from competing organisms in the environment. Collectively, these processes contribute to agricultural intensification which has been at least partly responsible for declines in farmland bird populations (Campbell et al. 1997; Uden et al. 2015).

Meeting increasing demand for ethanol requires increasing cropland in production, and consequently, the development footprint of biofuels is expected to be one of the fastest growing of all renewable energy sources in the next two decades (Johnson and Stephens 2011). Impacts of biofuel energy production on birds of prey occur primarily due to indirect effects triggered by the loss of breeding and foraging habitats when stands of trees used for nesting and open spaces used for hunting are converted to biofuel monocultures. Indirect effects include habitat loss, decreases in prey abundance, and potential biochemical effects from exposure to toxic chemicals. Direct effects are generally limited to rare occurrences of nestling mortality when nest trees are removed during breeding seasons, though exposure to bioaccumulating chemicals may also have effects that have not yet been identified.

Solar Facilities

Solar energy facilities also have the potential to impact birds of prey. Direct effects most often include electrocution on collection power lines, collisions with mirrors, and thermal trauma in solar flux fields (Kagan et al. 2014; McCrary et al. 1986). Electrocution can occur when a bird of prey simultaneously contacts two differently energized conductors or an energized conductor and a path to ground (APLIC 2006, in this book Chap. 12). Collisions occur when birds apparently mistake reflections of the sky in mirrors as the sky itself and attempt to fly through a mirror, perhaps in pursuit of prey.

Solar flux fields are the areas of concentrated light surrounding the collection tower(s) at thermal solar plants. Mirrors are used at these facilities to concentrate solar energy on a single area where water within a container is heated to produce steam which powers a generator. The air around the collection tower can reach 500–800 °C (McCrary et al. 1986; Diehl et al. 2016). Damage to feathers occurs at 160 °C (Wendelin et al. 2016), so flight through a solar flux field can result in burns to feathers and tissues, causing immediate mortality or limiting or eliminating the ability to fly, depending on individual exposure. Unlike other renewable energy technologies like wind turbines, which are relatively benign when not operational, solar flux fields can be dangerous to birds even when solar flux fields are not focused on collection towers (Wendelin et al. 2016). This can occur because mirrors in standby positions often focus solar energy just above collection towers. Heat in these standby positions can be intense enough to harm birds.

Morbidity and mortality of birds of prey in solar flux fields appear relatively rare, but when cases do occur, taxonomic patterns are emerging. Specifically, falcon (Falconiformes) species may be more susceptible, apparently because falcons are attracted to hunt aerial prey concentrated near collection towers (WEST 2016). Alternatively, in both active and standby positions, warm air rising above collection towers may attract buteos and vultures seeking thermal air currents to power flight, and these birds may inadvertently enter solar flux zones regardless of the presence or absence of potential prey.

Indirect effects of solar energy facilities include habitat loss, displacement, and avoidance (Hernandez et al. 2014). Unlike wind energy facilities where some of these effects might be temporary, with birds returning after construction, solar facilities eliminate habitat from within the facility, creating a flat bare earth-scape unattractive for hunting or nesting by birds of prey. Habitat loss at solar energy facilities is generally greater per megawatt generated than at wind facilities because wind resource areas retain most of the habitat below turbines, whereas solar facilities cover much of the facility in mirror arrays. Birds of prey and other wildlife species also may avoid habitats in and around solar facilities as a result of increased human activity and habitat alteration (DeVault et al. 2014).

Other Renewable Facilities

Other renewable energy sources include geothermal, hydroelectric, and oceanic. There are no substantial direct mortality effects to birds of prey documented for these energy sources. Geothermal power stations use heat energy from within the earth's crust to generate electrical energy. Facility footprints are similar to those of liquid and gas fossil fuel extraction facilities, with impacts to birds of prey limited to indirect effects resulting from disturbance during construction and operation. Roads to extraction wells increase habitat fragmentation (Jones and Pejchar 2013), impacting edge-sensitive species. Geothermal emissions often contain vaporized toxins which, while less than coal burning plants, release toxins into the air including hydrogen sulfide, carbon dioxide, ammonia, methane, and boron, mercury, and other heavy metals (Kagel et al. 2007), so indirect effects could also include reactions to toxic emissions.

Hydroelectric and oceanic renewable energy facilities use the energy of flowing rivers or tides to turn turbines and generate electricity. Hypothetically, aquatic hunters like osprey (*Pandion haliaetus*) could become entrapped in the machinery of hydroelectric or oceanic renewable energy infrastructure, but neither of these potential agents of mortality has yet been documented. This indicates that even if mortality occurs, levels are sufficiently low to preclude population impacts. Indirect effects likely do occur, though are not necessarily negative. Construction of reservoirs to store water for a hydroelectric dam floods and destroys bottomland habitats used as nest sites by some bird of prey species, but this habitat loss may be offset by creation of new reservoirs with far more shoreline hunting and nesting habitat than existed previously.

Effects of Transmission Linkages

Renewable facilities are connected to the existing electric system through construction of new transmission lines (Fig. 13.3), termed connections, interconnections, links, or linkages (hereafter interconnections). These interconnections have the potential to create avian collision and habitat fragmentation concerns well away from, but directly attributable to, renewable energy facilities. Post-construction environmental impacts of renewable energy infrastructure are generally considered only within the footprint of renewable energy facilities, but may not include the associated interconnections even though transmission lines are associated with avian collision mortalities (Bevanger 1998; Loss et al. 2014; Rogers et al. 2014). Because renewable interconnections have not yet been thoroughly studied with respect to potential impact to birds of prey, this section summarizes knowledge of potential impacts of transmission lines in general.

Direct effects of power lines on birds occur through mortality caused by electrocution and collision (Bevanger 1998; Loss et al. 2014). Electrocution is limited mostly to distribution lines (<69 kV) where clearances are minimal and birds can simultaneously contact multiple energized components or energized and grounded components (APLIC 2006, in this book Chap. 12). Transmission clearances designed to prevent electrical energy from arcing across conductors generally include separations greater than birds can bridge with extended wings, though there are exceptions on certain configurations used for lower transmission voltages (69–138 kV). Because electrocution is generally of little concern at the transmission voltages used in renewable energy interconnections, and because detailed

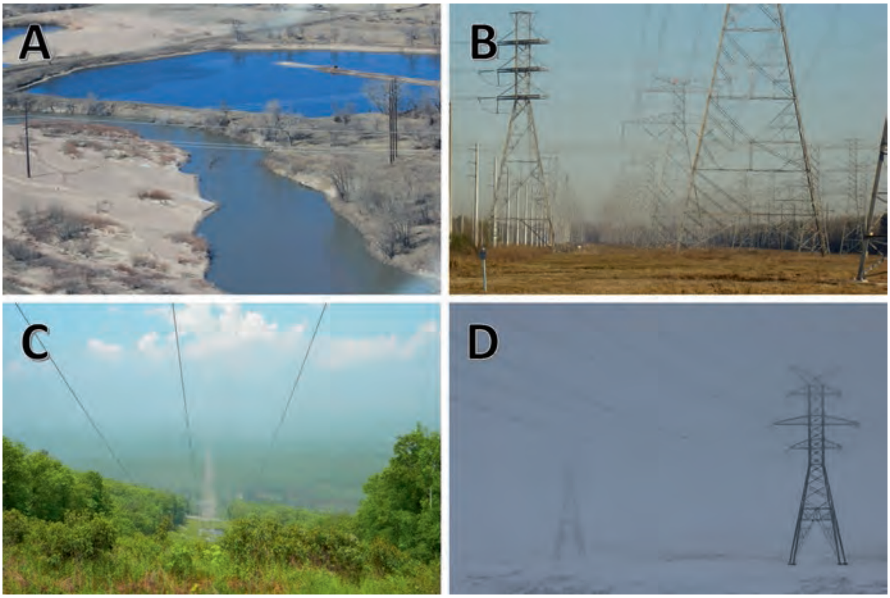

Fig. 13.3 Transmission line issues: (**a**) Transmission line bisecting a water source used by birds as a movement corridor. (**b**) Numerous transmission lines within a transmission corridor. (**c**) Overhead shield wires are less visible than conductors. (**d**) Transmission line partially obscured by fog

discussion of avian electrocution is available elsewhere in this book (in this book Chap. 12), this chapter does not address avian electrocutions.

Avian collision mortality is an ongoing global concern (Sporer et al. 2013; Rioux et al. 2013; Loss et al. 2014), though most research on the topic is not bird-of-prey-specific. Collisions involving transmission lines occur when a flying bird hits suspended wires, most often at night. Transmission lines are typically constructed with relatively thin overhead shield wires at the top and thicker energized conductors below. Birds appear to adjust flight altitudes upward to avoid large-diameter energized wires and then collide with smaller, less visible overhead shield wires (Murphy et al. 2016; Ventana Wildlife Society 2009; Martin and Shaw 2010). Transmission lines do not pose consistent risk. Rather, collision risk varies as a function of avian species and populations in the area of a given line, the surrounding habitat, and the line design (Bevanger and Brøseth 2004; Mojica et al. 2009; Rollan et al. 2010). Among birds, factors affecting collision risk include size, maneuverability, and flocking behavior (Jenkins et al. 2011; APLIC 2012). Transmission lines bisecting daily movement corridors, such as those located between roosting and foraging sites, also have been most associated with avian collisions (Bevanger and Brøseth 2004; APLIC 2012), with risk exacerbated during low-light, fog, and other inclement weather conditions (APLIC 2012; Hüppop and Hilgerloh 2012).

Birds of prey are at relatively low risk for power line collisions in general (SAIC 2000; Rioux et al. 2013), though large raptors with high wing loading and poor in-flight maneuverability like bustard species and condor species are collision prone.

In part, collision risk is low for birds of prey because they tend to fly diurnally during good weather (Ligouri 2005) and appear to detect and avoid transmission lines (Pope et al. 2006; Luzenski et al. 2016). Though risk for birds of prey is low compared to some other avian groups, collisions involving birds of prey do occur (Olendorff and Lehman 1986; Rollan et al. 2010, in this book Chap. 12). For example, California condors (*Gymnogyps californianus*) have collided with power lines (Snyder 2007), the Ventana Wildlife Society (2009) documented collisions by a northern harrier (*Circus cyaneus*) and a white-tailed kite (*Elanus leucurus*), and Mojica et al. (2009) documented multiple carcasses of bird of prey species (bald eagle (*Haliaeetus leucocephalus*), osprey, and owls) under distribution lines. Studies have shown certain African birds of prey are vulnerable to colliding with lines in foraging habitats (Boshoff et al. 2011; Rollan et al. 2010). Peregrine falcons can be at risk because they attain high speeds when pursuing prey near the ground (Olendorff and Lehman 1986). Mañosa and Real (2001) documented both collisions of breeding Bonelli's eagle (*Hieraaetus fasciatus*) and high turnover rates of pairs nesting within 1 km of power lines in Catalonia, Spain. González et al. (2007) documented infrequent collision as a cause of mortality in a study examining 267 records of nonnatural mortality of the Spanish imperial eagle (*Aquila adalberti*).

Indirect effects of transmission lines on birds of prey are not well studied but are likely low following initial disturbance and acclimation during and following construction given the fact that many birds of prey readily nest on or near transmission lines. Transmission lines can create corridors for human incursion into otherwise natural landscapes because maintenance access roads and rights-of-way may be used for recreational activities (hiking, running, mountain biking, cross-country skiing, all-terrain vehicles, etc.). Some bird of prey species respond negatively to recreational human traffic (Steidl and Anthony 1996), but no firm connection has yet been established to confirm widespread impacts with respect to power lines.

Power lines generate strong electromagnetic fields, UV discharges, and acoustic signatures which can affect animal health and behavior (Phernie et al. 2000; Tyler et al. 2014). Recent research suggests that avoidance by reindeer (*Rangifer tarandus*) may be linked to their ability to detect ultraviolet light emitted by transmission lines (Tyler et al. 2014). At least some birds also see in the ultraviolet spectrum (Lind et al. 2014), but the potential implications of this for indirect effects have not been investigated in birds of prey (in this book Chap. 12).

Offsite Effects

Offsite effects are indirect by definition. The natural resources used in constructing renewable infrastructure are typically harvested from areas well beyond the boundaries of renewable project sites. This has the potential to shift some of the environmental costs of renewable energy away from project sites where resources are used, to mine and factory sites where resources are extracted and processed. Consequently, offsite mining should be considered when developing a comprehensive understanding of potential impacts of renewable energy sources on birds of prey.

Effects of mines on birds of prey are site-specific and species-specific. For example, peregrine falcons and gyrfalcons (*Falco rusticolus*) breeding near two diamond mines in Northwest Territories, Canada, showed no difference in nest occupancy or breeding success as a function of distance from mine footprints, despite those footprints expanding during the study (Coulton et al. 2013). In contrast, prairie falcons (*Falco mexicanus*) in New Mexico appeared to avoid an entire mountain range where mining and blasting for various minerals was common but did nest in two adjacent ranges with similar habitats but less mining activity (Bednarz 1984). Mild responses to the vibration and noise associated with mining may derive from the occurrence of such natural events as thunder and landslides (Holthuijzen et al. 1990), with which birds of prey are presumably familiar both individually and over evolutionary time. Across studies, with few exceptions, evidence of disturbance by mining activity seems isolated and in some cases can be offset by relocating birds of prey nests prior to the advance of mine operations (McKee 2007). However, at least some mine sites likely included nesting territories prior to initiation of mining activities. In these cases, productivity from directly affected territories likely was reduced at least while affected individuals sought alternate nest sites. Even these impacts may be minimized, however, with measures specifically designed to support birds of prey populations, for example, through installation during reclamation of permanent structures designed to serve as nest substrates (Harshbarger 1997) and through the use of unreclaimed anthropogenic cliffs used for nesting (Moore et al. 1997). Mines also are associated with environmental pollution. Mining and smelting can lead to increased levels of lead in ospreys and American kestrels (*Falco sparverius*) nesting downstream (Henny et al. 1991, 1994) and in Eurasian eagle owls (*Bubo bubo*; Espin et al. 2014), though to our knowledge, definitive links to survival or productivity specifically related to mine sites have not been established. Though reductions in nesting attempts or productivity appear minimal overall, spills, pollution, and sedimentation from mine sites may have effects that are difficult to link conclusively to evidence of impacts specifically affecting birds of prey.

Though mining does have deleterious ecological consequences, and some examples involving birds of prey can be identified, overall it appears that offsite indirect impacts are either small or difficult to quantify and isolate (Anderson et al. 2008). Regardless of potential effects associated with renewable infrastructure, mined materials would also be necessary for fossil fuel extraction, which renewable energy facilities are designed to replace. That being so, it appears that indirect effects of extractive industries on birds of prey are minimal and offset by equivalent needs across energy sources.

Mitigation

Renewable energy facilities have the potential to bring together ecologically novel combinations of juxtaposed land covers like water bodies in deserts, prominent features like tall perches where none existed naturally, potential risks to wildlife like electrocution and mirror collisions, and potentially, unique combinations of species drawn to these features from their respective native habitats. Consequently, the removal and addition of biotic and abiotic materials at renewable energy facilities may require novel mitigation strategies applied to microclimates and biological communities which may not occur naturally. The rotor-swept zones of wind resource areas and the heated-air zones of solar tower collection areas have no natural analogues and thus no evolutionary context preparing wildlife for the risks encountered in these areas.

It should be incumbent on those creating these new landscapes, to also provide new and effective mitigation. With regard to mitigation of bird of prey mortalities at wind resource areas, innovative techniques are being developed to compensate for mortality at the renewable sites by mitigating the electrocution of birds of prey elsewhere (Fig. 13.4), creating a net benefit overall (USFWS 2013).

Wind energy facilities can also adjust turbine operations to prevent collisions by curtailing operations when birds of prey are flying within the wind resource area, and by increasing minimum operational wind speeds to wind speeds above those within which birds of prey generally choose to fly (USFWS 2013). At solar facilities with collection towers, successful mitigation involves spreading the aim points of mirrors apart to reduce the peak flux value to <4 kW/m^2 when the facility is in standby mode and not actively producing power (Multiagency Avian-Solar Collaborative Working Group 2016). For both wind resource areas and solar facilities, direct and indirect effects may be minimized by siting facilities away from

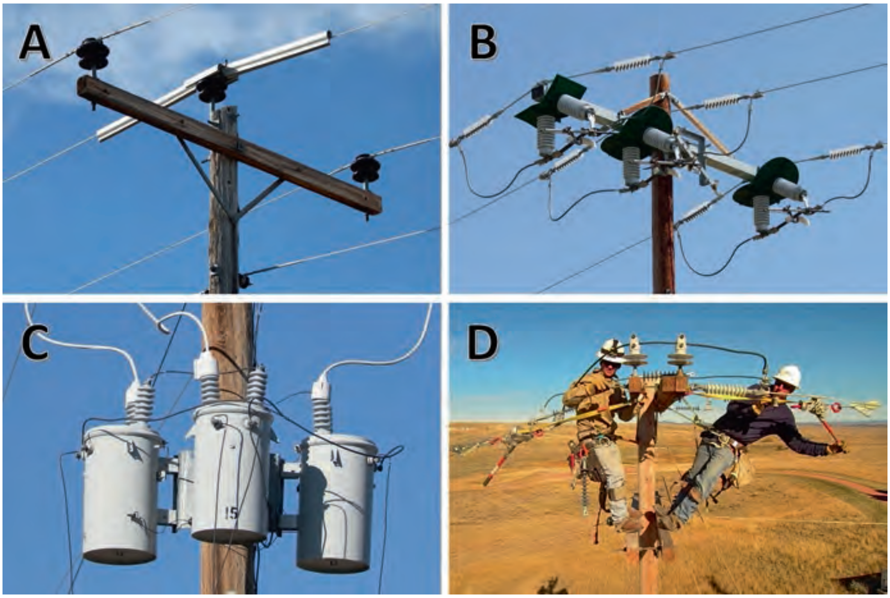

Fig. 13.4 Retrofitted power poles: (**a**) Insulation on center wire. (**b**) Insulation on connecting wires and on switches. (**c**) Insulation on connecting wires and on energized components of equipment. (**d**) Installation of insulation on equipment. (See in this book Chap. 12 for additional technical details on electrocution of birds of prey)

concentrated populations of birds of prey at migration, foraging, or roosting sites. Collisions involving birds of prey and transmission interconnections can be mitigated by marking transmission lines to increase their prominence to approaching birds of prey so lines can be avoided (in this book Chap. 12).

Unlike compensation programs for wind and solar energy, which are still in their infancy, compensation programs for biofuel monocultures are well established within a general framework of minimizing agricultural impacts to natural systems to the extent practical. Mitigation for biofuel monocultures may be achieved through existing mitigation programs, such as the US Department of Agriculture's Conservation Reserve Program which enables farmers to remove environmentally sensitive land from agricultural production in exchange for an annual payment. These types of programs tend to be successful if three obstacles can be overcome. First, because participation is voluntary, individual decisions may be influenced by the value of the payment compared to the value of potential crop yields. This mitigation strategy may lose effectiveness if demands for biofuels, and other crops competing in the market place for the same land, result in crop profits per acre that are greater than payments (Johnson and Stephens 2011). Second, compensation may undermine an individual's sense of responsibility for the land (Ramsdell et al. 2016), potentially resulting in a reduced sense of stewardship over the long term and enabling landowners to justify conversion of natural habitats if compensation programs terminate. Third, compensation programs may not be practical in developing countries lacking the necessary financial or political resources. Despite the potential obstacles involved in compensation-based mitigation programs, these solutions are nevertheless the best currently available, at least in areas like the USA where most arable farmland is privately owned and decisions affecting land use are primarily market driven. Though not necessarily focused on bird of prey concerns, these approaches often result in habitat patches that can contain hunting habitat or potential nest sites, creating focal locations which allow bird of prey populations to persist within areas dominated by agriculture.

Siting new facilities in previously disturbed habitat like nonproductive agricultural fields also can reduce impacts to birds from loss of breeding and foraging habitat (Pearce et al. 2016). Birds of prey can be intentionally displaced from solar projects when nesting sites are destroyed during construction. Burrowing owls (*Athene cunicularia*) have been successfully translocated to new breeding sites away from solar facilities (Multiagency Avian-Solar Collaborative Working Group 2016).

Benefits to Birds of Prey

Birds of prey also can benefit from renewable energy facilities and transmission linkages, primarily through provision of new nesting opportunities (Fig. 13.5) since birds of prey routinely nest on transmission structures. For example, bald eagles and osprey regularly nest on utility structures (Buehler 2000; Poole et al. 2002).

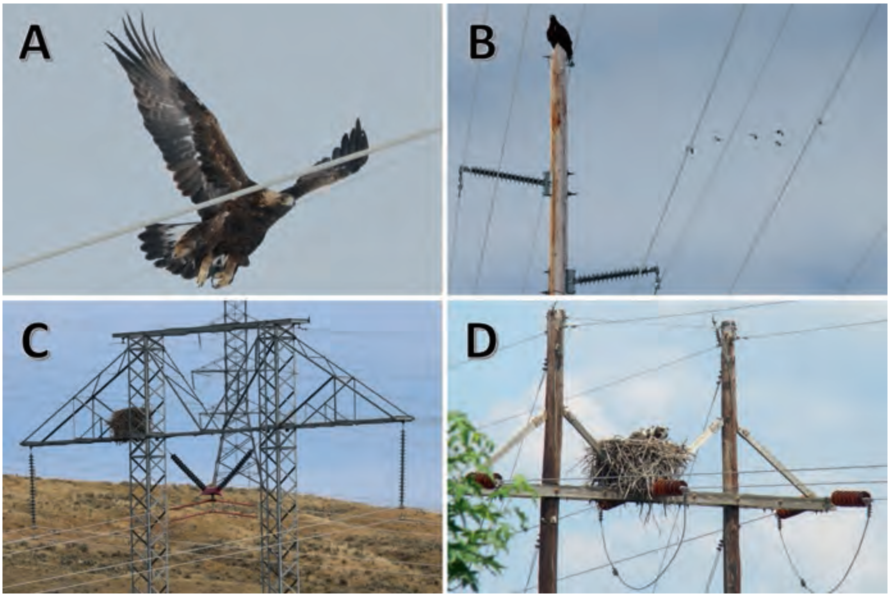

Fig. 13.5 (**a**) A golden eagle (*Aquila chrysaetos*) departing a transmission tower, potentially benefitting through hunting opportunities and, simultaneously, potentially at risk of collision with transmission wires. (**b**) A golden eagle roosting atop a transmission pole. (**c**) A golden eagle nest on a transmission tower. (**d**) An osprey (*Pandion haliaetus*) nest on a transmission H-frame structure

Other species nesting on utility structures include ferruginous hawks (*Buteo regalis*; Gilmer and Wiehe 1977), hobbies (*Falco subbuteo*; Puzović 2008), common kestrels (*Falco tinnunculus*; Krueger 1998), greater kestrels (*Falco rupicoloidesa*; Ledger and Hobbs 1999), martial eagles (*Polemaetus bellicosus*; Jenkins et al. 2013), prairie falcons (Roppe et al. 1989), lanner Falcons (*Falco biarmicus*; Ledger and Hobbs 1999), upland buzzards (*Buteo hemilasius*; Ellis et al. 2009), Swainson's hawks (*Buteo swainsoni*; James 1992), tawny eagles (*Aquila rapax*; Jenkins et al. 2013), black eagles (*Aquila verreauxii*; Jenkins et al. 2013), African hawk eagles (*Hieraaetus fasciatus*; Ledger and Hobbs 1999), and white-backed vultures (*Gyps africanus*, Ledger and Hobbs 1999). Though none of these were on renewable interconnections, the consistency between transmission structures in general and transmission structures supporting renewable interconnections specifically indicates that nesting is likely. Nesting habitat can also be created from mines providing new nest substrates for cliff-nesting birds of prey like peregrine falcons (Moore et al. 1997). Habitat conversion for dams and agriculture can also increase food availability for birds of prey because dams and reservoirs create aquatic habitat and provide abundant year-round food resources for birds of prey including water snakes (Tingay et al. 2010), waterbirds (Mukherjee and Wilske 2006; Mwaura et al. 2002), and stunned or dead fish flowing through dam spillways or turbines (Sánchez-Zapata et al. 2016).

Integrated vegetation management techniques employed in rights-of-way management for renewable energy interconnections can also play an important role in maintaining and improving habitat for wildlife (Ball 2012; Rogers 2016). These activities could create hunting habitat for birds of prey or be used as migration corridors (Denoncour and Olson 1982).

Other indirect benefits may also be important. The fundamental motivators of shifting global economies from fossil fuels to renewable energies are national energy independence and reduction of greenhouse gas emissions. Energy independence is perhaps irrelevant to birds of prey, but reduction of greenhouse gas emissions and global climate change do have substantial potential benefits for birds of prey. Global climate change is associated with increased frequency and intensity of weather events. Late spring and high-intensity weather events can directly impact the productivity and survival of birds of prey. For example, breeding success is negatively correlated with precipitation during nesting in peregrine falcons (Anctil et al. 2014; Burke et al. 2015). Survival of peregrines migrating south from the Artic is negatively correlated with climatic events suggesting the species is vulnerable to weather events along the migration route (Franke et al. 2011). Reduced impacts of climate change in general will likely reduce weather-related impacts on nesting birds of prey.

Conclusions

Ultimately, the large, widely dispersed territories of most birds of prey minimize the population impacts of either direct or indirect effects at most renewable energy facilities, transmission interconnections, or mines. This is because even if a specific territory is affected by a renewable energy facility, through habitat loss, for example, the effect is unlikely to have a population-level effect. There are exceptions however. For example, collisions involving migrating or wintering birds of prey with wind turbines can result in impacts dispersed throughout breeding ranges, and large-scale biofuel monocultures can result in elimination of habitat patches far larger than a single territory. These two areas of renewable energy advancement in particular warrant ongoing consideration, mitigation, and monitoring as renewable energy facilities expand into the habitats of birds of prey.

Acknowledgments We thank R.E. Harness for insights which guided this writing and EDM International, Inc. (Fort Collins, CO) for providing funding and logistical support.

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EXHIBIT
9

Management and Conservation Article

Avian and Bat Fatality Rates at Old-Generation and Repowered Wind Turbines in California

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ABSTRACT Wind turbines in the Altamont Pass Wind Resource Area (APWRA), California, USA, have caused annual fatalities of thousands of raptors and other birds. Alameda County implemented an Avian Protection Program requiring mitigation measures and eventual repowering to modern wind turbines, all intended to reduce raptor fatality rates 50% from levels estimated for 1998–2003. Two years into the 3-year program, we compared estimates of fatality rates between 1998–2003 and 2005–2007 and between a repowered wind project (Diablo Winds) and the APWRA's old-generation wind turbines. The APWRA-wide fatality rates increased significantly for multiple bird species, including 85% for all raptors and 51% for all birds. Fatality rates caused by the Diablo Winds repowering project were not lower than replaced turbines, but they were 54% and 66% lower for raptors and all birds, respectively, than those of concurrently operating old-generation turbines in 2005–2007. Because new-generation turbines can generate nearly 3 times the energy per megawatt of rated capacity compared to the APWRA's old turbines, repowering the APWRA could reduce mean annual fatality rates by 54% for raptors and 65% for all birds, while more than doubling annual wind-energy generation. Alternatively, the nameplate capacity of a repowered APWRA could be restricted to 209 megawatts to meet current energy generation (about 700 gigawatt-hr), thereby reducing mean annual fatalities by 83% for raptors and 87% for all birds. In lieu of repowering, bird fatalities could be reduced by enforcing operating permits and environmental laws and by the County requiring implementation of the Alameda County Scientific Review Committee's recommendations. (JOURNAL OF WILDLIFE MANAGEMENT 73(7):1062–1071; 2009)

DOI: 10.2193/2008-464

KEY WORDS Altamont Pass, bird fatalities, mitigation, raptor mortality, repowering, wind energy, wind turbine.

The Altamont Pass Wind Resource Area (APWRA) began operations during the 1980s and was until recently the world's largest wind farm, with a permitted generating capacity of 580 megawatts (MW). It supplies emission-free electric power to thousands of homes, but many of the thousands of dead birds found by the wind turbines are protected by the Migratory Bird Treaty Act (MBTA) and some are protected by other state and federal laws (Appendix). Smallwood and Thelander (2008) estimated bird fatality rates in the APWRA during 1998–2003, but those estimates preceded some repowering and implementation of mitigation measures to reduce wind turbine–caused fatalities.

In 1998 the APWRA included about 5,400 wind turbines of various models, ranging in capacity from 40 kilowatts (kW) to 400 kW but most were 100 kW to 150 kW. In February 2005 the Diablo Winds Energy Project repowered 21 MW of rated capacity by replacing 126 Flowind (FloWind Corp., San Rafael, CA) vertical-axis wind turbines with 31 Vestas (Vestas Wind Systems A/S, Randers, Denmark) horizontal axis wind turbines (Table 1). The new turbines were more widely spaced and operated at lower rotor speed (rotations/min), which were traits thought by some to be safer for birds (Erickson et al. 2001, Tucker 1996). Hunt (2002) concluded repowering with larger turbines would be safer for golden eagles (*Aquila chrysaetos*), but Orloff and Flannery (1992) and Smallwood and Thelander (2004, 2005) found that turbines with larger rotor-swept areas killed more of some raptor species.

In August 2005, Alameda County renewed the conditional use permits held by most APWRA wind companies, requiring new, more stringent mitigation measures to reduce wind turbine–caused fatality rates. This Avian Protection Program was to be assessed through November 2009 by an avian monitoring team and Scientific Review Committee (SRC). The program was modified in January 2007 following a settlement agreement to litigation brought by environmental groups, including a goal to reduce wind-turbine–caused raptor fatalities by 50% since the 1998–2003 study (Smallwood and Thelander 2008), where raptors were represented by 4 target species: golden eagle, red-tailed hawk (*Bueo jamaicensis*), American kestrel (*Falco sparverius*), and burrowing owl (*Athene cunicularia*).

By November 2007, wind companies implemented some mitigation measures required by County use permits and recommended by the SRC (Table 2). Our objectives were to compare estimates of APWRA fatality rates between 1) the periods 1998–2003 and 2005–2007, and 2) a repowered wind project and the concurrently operating old-generation wind turbines.

STUDY AREA

The APWRA encompassed about 165 km^2 of ridges and hills generally extending northwest to southeast and bisected by intermittent streams and ravines in eastern Alameda and southeastern Contra Costa counties, California, USA. Elevations ranged 78 m to 470 m above mean sea level. Slopes were covered mostly by nonnative, annual grasses, which grew during the rainy months of January through March and were dead or dormant by early June. Cattle grazers held most of the land, leasing out wind-energy rights to wind-power companies.

Wind turbines were arranged in rows of up to 62 turbines, typically along ridge crests (i.e., peaks of the ridge features)

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Table 1. Attributes of wind turbines involved in the Diablo Winds Energy Project, which repowered 21 megawatts (MW) of rated capacity in the Altamont Pass Wind Resource Area, California, USA, in February 2005.

Attribute	Repowered Flowind[a] vertical-axis turbines		New Vestas[b] horizontal axis turbines	
Model	F-17	F-19	V47	V47
No. turbines	105	21	24	7
Rated output/turbine (MW)	0.15	0.25	0.66	0.66
No. of blades	2	2	3	3
Rotor diam (m)	17.2	19.1	47	47
Rotor speed (revolutions/min)	66.3	59.7	28.5	28.5
Hub ht above ground (m)			50	55
Highest blade reach above ground (m)	29.5	32.3	73.5	78.5
Lowest blade reach above ground (m)	4	4	26.5	31.5
Inter-turbine spacing within rows (m)	51	51	104	104

[a] FloWind Corp., San Rafael, California, USA.
[b] Vestas Wind Systems A/S, Randers, Denmark.

and ridgelines extending down toward ephemeral streams. Wind turbine rows also occupied slopes, valleys, and hill peaks, and all operated in winds from any direction, although most winds originated from the southwest or northwest. Old-generation wind turbine models were listed in Smallwood and Thelander (2008).

METHODS

We performed fatality searches at 2 sets of wind turbines during 1998–2003 (Table 3). We searched all set 1 turbines, because they were the only turbines to which the companies granted access until 2002, when all other turbines became available for fatality monitoring. We systematically selected set 2 turbines from the remaining pool of turbines to ensure homogenous interspersion of searched and unsearched turbines across the north to south and east to west extents of the APWRA (Smallwood and Thelander 2008). Altogether, we searched 4,074 (75%) of the 5,400 turbines in the APWRA during 1998–2003. Within set 1, we also searched all 126 Flowind vertical-axis turbines (21 MW) in 25 rows with an average interval of 45 days. These turbines ceased operations in 2000–2001 and were replaced in 2005 by 31 modern Vestas V47 turbines (20.46 MW) as part of the Diablo Winds Energy Project repowering (Table 3). Also within set 1, we searched 899 turbines (81.63 MW) that we selected randomly for the 2005–2007 fatality monitoring and so were directly comparable between monitoring periods.

We performed fatality searches since 2005 at 2,650 (53%) of the APWRA's old-generation wind turbines (Table 3). Fatality searches were within 84 randomly selected plots stratified by north and south aspects of the APWRA and by turbine size (i.e., very small: 40–65 kW; small: 100–150 kW; and medium: 250 kW). Each plot included 10–60 turbines in 1–7 rows. To estimate APWRA-wide fatality rates during 2005–2007, we extrapolated estimates from turbines in randomly selected plots to the 547.02 MW of rated capacity from which we drew our old-generation

Table 2. Implementation of Alameda County Avian Protection Program to reduce avian fatality rates in the Altamont Pass Wind Resource Area, California, USA, 22 September 2005 through 31 October 2007.

Mitigation measure (required by permit or recommended by Alameda County Scientific Review Committee [SRC])	Action taken
Convene SRC by 31 Oct 2005 (Permit).	SRC convened on 11 Sep 2006.
Remove or relocate turbines classified (K. S. Smallwood and L. Spiegel, California Energy Commission, unpublished data) as Tier 1 (most hazardous) by 31 Oct 2005 and as Tier 2 by 9 Feb 2007 (Permit).	Most operated in Apr 2007 and some operated in Sep 2007. No confirmed determination of removals or relocations through Nov 2007.
Remove vacant towers and towers supporting broken turbines, 50% by 22 Mar 2006 and 100% by 22 Sep 2006 (Permit).	Vacant towers and towers with broken turbines were not removed.
Subject to approval by United States Fish and Wildlife Service, remove all artificially created rock piles away from turbines by 20 Mar 2006 (Permit).	Rock piles were not removed.
Implement other on-site measures recommended by Smallwood and Thelander (2004) and SRC by 20 Mar 2006 (Permit).	None were implemented (see below).
Cease rodent control activities on all sites.	Wind companies stopped funding rodent control, but some land owners likely continued control efforts.
Pending SRC approval of an experimental design, paint turbine blades using Hodos (2003) scheme on a trial or larger basis (Permit). The intent was to lessen motion smear caused by moving wind turbine blades.	One company painted one blade black on 42 turbines, but without using the correct paint or obtaining SRC approval due to experimental design concerns.
Winter-time shut-down of turbines in a cross-over design, so northern turbines were to shut down during 2 months of winter and the southern turbines operated, and vice versa during winter's second half; the shut-down order was to switch between the winters of 2005–2006 and 2006–2007 (Permit).	Shut-downs were completed, but the permit requirement deviated from the original recommendation for a 4-month winter shut-down (K. S. Smallwood and L. Spiegel, unpublished data).
Remove vacant lattice towers used as end-of-row flight diverters (SRC).	Vacant towers were not removed.
Provide turbine power output data so the SRC can test hypotheses of causal mechanisms and more effectively recommend turbine removals (SRC).	No power output data were provided during our study.
Repowering should be pursued to reduce avian fatality rates (SRC).	No repowering was pursued during our study.

Table 3. Attributes of wind turbines and avian and bat fatality searches compared between 1998–2003 and 2005–2007 and within land held by East Bay Regional Park District (EBRPD), Altamont Pass Wind Resource Area, California, USA.

Attributes	Monitoring period 1998–2003 Smallwood and Thelander (2008)		Monitoring period 2005–2007 Consultants to Alameda County (Avian Protection Program)			Monitoring period 2005–2007 Smallwood et al. (2009)
Sample	Set 1	Set 2	Group 1	Group 2	Diablo Winds	EBRPD
Start and end dates	Mar 1998–Sep 2002	Nov 2002–May 2003	Oct 2005–Oct 2007	Mar 2007–Oct 2007	Apr 2005–Nov 2007	Jun 2006–Sep 2007
Duration (yr)	1.5–4.5	0.5	2	0.6	2.7	1.3
Sample selection	Census	Systematic	Random	Random	Census	Census
Turbine models	All available	All available	Old-generation	Old-generation	Vestas V47	Nordtank, Howden
Turbine sizes (kilowatts)	40–400	65–400	40–400	100–120	660	65 & 330
No. turbines	1,526	2,548	2,114	536	31	62
Rated capacity (megawatts)	153.25	267.09	212.62	54.34	20.46	12.52
Search radius (m)	50	50	50	50	75	60
Mean search interval (days)	53	>90	41	41	33	17

turbine sample. Three complications emerged from this sampled pool. In 2005, the Buena Vista Wind Energy project replaced 179 small wind turbines in Contra Costa County with 38 1-MW Mitsubishi turbines. It began operations in January 2007, but fatality monitoring by other investigators did not begin there until January 2008. We assumed fatality rates were similar between the Buena Vista project and the rest of the sampled pool of turbines, but we cannot validate the accuracy of our assumption. A second complication was an infrastructure problem that resulted in shutting down all 200 Vestas 100-kW turbines owned by the City of Santa Clara from November 2005 through February 2007, except for January 2006. We searched for fatalities at 12.8 MW (128 turbines) of this 20 MW of capacity, despite nonoperation. The third complication was refused access to 186 turbines (12.1 MW capacity) owned by Northwind Inc. in Contra Costa County. However, East Bay Regional Park District (EBRPD) allowed us to use estimates of fatality rates from EBRPD property (Smallwood et al. 2009), which included about 12% of the Northwind Inc. turbines. To the estimates of fatality rates extrapolated to 547.02 MW of capacity, we added estimates from 12.52 MW of capacity on the EBRPD property and 20.46 MW in the Diablo Winds project.

Searches were performed by biologists walking parallel transects about 4–8 m apart, viewing all ground out to 50 m at most old-generation wind turbines, 60 m at the 330 kW Howden turbines, and 75 m at the 660 kW Diablo Winds turbines. We documented as fatalities all carcasses or body parts found, such as groups of flight feathers, head, wings, tarsi, and tail feathers. When possible, we identified carcasses to species, age class, and sex. We assessed carcass condition to estimate number of days since death. Generally we assumed carcasses were older than 90 days if the enamel on culmen and talons had separated from the bone, flesh was gone, and bones and feathers were bleached, but we used judgment because carcass decomposition rates vary according to environmental conditions. Presence of blood generally indicated <4 days since death, but onset of rigor mortis, odor, and maggots or other insect larvae varied greatly with temperature, so we had to use these signs as guides in the context of current environmental conditions to estimate number of days since death. We photographed nearly all carcasses.

We considered each fatality record as unlikely, possibly, probably, or certainly caused by wind turbines. Fatalities unlikely caused by turbines were unfledged birds or those determined to have been caused by electrocution, vehicle collision, or predation. They were possible if within the fatality search radius but nearby an electric distribution pole or lines, implicating electrocution or line strike as causes of death, or if they were burrowing owls next to burrows, implicating predation. They were probable if found near wind turbines and another cause of death was not determined. They were certain if evidence suggested a turbine was involved, such as oil or grease on the bird, paint on the bird, or the bird was split in two or dismembered due to impact. We considered most of the fatalities found probably caused by wind turbines, 71% during 1998–2003 and 91% during 2005–2007. To estimate turbine-caused fatality rates we used fatalities considered possibly, probably, or certainly caused by wind turbines, or 98.6% of fatalities reported in 1998–2003 and 97.3% in 2005–2007.

Within each turbine row we expressed unadjusted fatality rate (F_U) as number of fatalities per MW per year, where we summed MW across all turbines in the row. Although individual turbines killed birds, we used the wind turbine row as our study unit because 1) we believed birds often sensed and reacted to the wind turbine row as a barrier or threat, and 2) we often could not determine which turbine in the row killed the bird. We used the MW of rated capacity of all turbine addresses initially searched within the row, regardless of whether the address later supported a functional or broken turbine or a vacant tower. We took this approach because we were not regularly updated on turbine functionality, which varied, and we were often unable to determine functionality while wind speeds were too low for power generation. To number of years in the fatality-rate calculation, we added average search interval (in days converted to yr) to represent the time period when carcasses could have accumulated before our first search. We derived fatality-rate estimates from fatalities estimated to have occurred $\leq$90 days before discovery. We discovered most excluded fatalities during start-up searches at newly visited turbines. Out to 125 m, we included carcasses found outside the search radius because we assumed likelihood of seeing carcasses outside the search radius would not vary significantly among turbine rows in the APWRA's short-stature grassland.

We adjusted our fatality-rate estimate, F_A, for carcasses not found due to searcher-detection error and scavenger removals as

$$F_A = \frac{F_U}{p \times R_C} \tag{1}$$

where F_U was unadjusted fatality rate, p was proportion of fatalities found by searchers during searcher-detection trials in grasslands across the United States and reported in Smallwood (2007), and R_C was estimated cumulative proportion of carcasses remaining since the last fatality search, assuming wind turbines will deposit carcasses at a steady rate through the search interval. We estimated R_C by scavenger-removal rates estimated from trials throughout the United States and averaged by Smallwood (2007):

$$R_C = \frac{\sum_{i=1}^{I} R_i}{I} \tag{2}$$

where R_i was proportion of carcasses remaining by the ith day following initiation of a scavenger-removal trial (intended to correspond with no. of days since the last fatality search during monitoring), and I was average search interval (days). We looked up R_C values in Smallwood (2007; Appendix) according to species group and search interval. We calculated standard error of the adjusted fatality rate, SE[F_A], using the delta method (Goodman 1960):

$$\mathrm{SE}[F_A] = \sqrt{\left(\frac{1}{p \times R_C} \times \mathrm{SE}[F_U]\right)^2 \times \left(\frac{F_U}{p} \times \frac{-1}{{R_C}^2} \times \mathrm{SE}[R_C]\right)^2 \times \left(\frac{F_U}{R_C} \times \frac{-1}{p^2} \times \mathrm{SE}[p]\right)^2} \tag{3}$$

We did not adjust estimates for background mortality, crippling bias, or search radius bias. Background mortality is the fatality rate caused by factors other than wind turbines and supporting infrastructure. Crippling bias refers to the rate of mortally wounded animals dying undetected outside the search radius or moving from unsearched turbines to searched turbines. Search-radius bias refers to the rate of wind turbine–killed birds thrown beyond the search radius and not found. Birds thrown 50 m laterally from turbines atop steep slopes can land farther down the hill than the 50 m measured from the searcher to the turbine base.

Differing from Smallwood and Thelander (2008), we included carcasses removed by companies as part of the Wildlife Response and Reporting System (WRRS), which was the industry's system of reporting carcasses found incidentally by turbine maintenance personnel. As a result, our 1998–2003 estimates reported herein will sometimes differ from Smallwood and Thelander (2008). Including WRRS data undoubtedly introduced some small error in our fatality-rate estimates because we applied the same scavenger-removal adjustments to these few fatalities as to the carcasses detected during our standard fatality searches.

We estimated bat fatality rates by applying scavenger-removal and searcher-detection rates estimated for small-bodied bird species (Smallwood 2007). However, numerous unpublished reports found that searchers miss more bats than small birds, and scavengers quickly remove many bats. Therefore, our estimates of bat fatality rates were likely biased low, but at least they were consistent between estimates reported herein, enabling preliminary comparisons between time periods and turbine fields.

Due to complexity of the APWRA-wide estimates of fatality rates, including 2 sampling approaches during 1998–2003 and multiple separate estimates added together in 2005–2007, we did not test for APWRA-wide differences in fatality rates. Instead, we simply compared estimated means and standard errors between monitoring periods. We used the t-test to test whether mean fatality rates differed between 1998–2002 and 2005–2007 within the 81.63 MW of turbines that were directly comparable (reference turbines) and within the 21 MW of the repowered Diablo Winds turbines.

RESULTS

APWRA-Wide Fatality Rates

Between 1998–2003 and 2005–2007, estimated mean adjusted fatality rate decreased 40% for American kestrel and increased 121% for red-tailed hawk, 17% for golden eagle, 30% for burrowing owl, 10% for all 4 target species combined, and 23% for all birds combined (Appendix). However, we did not test these mean differences for significance due to differences in sampling designs leading to the APWRA-wide fatality-rate estimates.

Comparing adjusted fatality rates only from old-generation turbines mutually monitored during both 1998–2003 and 2005–2007, fatality rates increased 110% for burrowing owl, 247% for barn owl (*Tyto alba*), 163% for rock pigeon (*Columba livia*), and 94% for western meadowlark (*Sturnella neglecta*), but not significantly for any other species (Table 4). Fatality rates increased 81% for the 4 target species together, 85% for all raptors, and 51% for all birds. Estimated mean fatality rate of red-tailed hawk increased 79%, but this increase was not significant.

Diablo Winds Fatality Rates

The first repowering project in the APWRA did not change fatality rates for any species or group of species, because fatality rates did not differ between the old vertical-axis turbines and the new horizontal axis turbines (Table 5). Though not significant, mean adjusted fatality rate increased for golden eagle from zero at the vertical-axis turbines in 1998–2001 to one eagle in 3 years during 2005–2007. Mean adjusted fatality rate increased 124% for red-tailed hawk, but decreased 13% for American kestrel, 21% for burrowing owl, 12% for all 4 target species together, and 25% for all

Table 4. Comparison of mean fatality-rate estimates at wind turbines mutually searched during both the 1998–2002 and in 2005–2007 monitoring programs, using 2-tailed paired-sample *t*-tests (df = 109). We searched turbines 1.5–4.5 years (most >2 yr) in 1998–2002 and 2 years in 2005–2007. Turbines totaled 81.63 megawatts (MW) of rated capacity in 110 rows, mostly in the central, eastern, and southern aspects of the Altamont Pass Wind Resource Area, California, USA.

	Adjusted fatality-rate (deaths/MW/yr)					
	1998–2003		2005–2007			
Species[a]	$\bar{x}$	SE	$\bar{x}$	SE	Paired-sample *t*-value	*P*-value
Turkey vulture	0.009	0.009	0.003	0.003	0.676	0.500
Golden eagle	0.070	0.024	0.091	0.035	0.499	0.619
Red-tailed hawk	0.437	0.121	0.782	0.148	1.756	0.082
Buteo spp.	0.000	0.000	0.016	0.015	1.083	0.281
Northern harrier	0.006	0.003	0.015	0.011	0.864	0.389
Prairie falcon	0.003	0.003	0.006	0.004	0.608	0.545
American kestrel	0.496	0.147	0.532	0.146	0.172	0.864
Burrowing owl	1.442	0.345	3.025	0.524	2.690	0.008
Great horned owl	0.043	0.023	0.048	0.026	0.149	0.882
Barn owl	0.077	0.027	0.268	0.065	2.663	0.009
Double-crested cormorant	0.017	0.017	0.000	0.000	1.000	0.320
Great blue heron	0.000	0.000	0.004	0.004	1.000	0.320
Great egret	0.000	0.000	0.156	0.156	1.000	0.320
Killdeer	0.000	0.000	0.012	0.012	1.000	0.320
Black-necked stilt	0.000	0.000	0.130	0.130	1.000	0.320
American avocet	0.059	0.049	0.000	0.000	1.186	0.238
Gull spp.	0.030	0.019	0.122	0.049	1.987	0.049
Ring-billed gull	0.029	0.024	0.000	0.000	1.229	0.222
California gull	0.028	0.016	0.035	0.035	0.173	0.863
Duck spp.	0.000	0.000	0.017	0.017	1.000	0.320
Mallard	0.187	0.065	0.137	0.090	0.824	0.412
Northern flicker	0.247	0.157	0.087	0.090	0.888	0.377
Wild turkey	0.013	0.013	0.000	0.000	1.000	0.320
Dove spp.	0.000	0.000	0.101	0.052	1.952	0.054
Rock pigeon	1.339	0.340	3.520	0.642	3.846	0.000
Mourning dove	2.538	0.943	1.054	0.305	1.488	0.140
White-throated swift	0.000	0.000	0.027	0.027	1.000	0.320
American crow	0.068	0.044	0.049	0.031	0.345	0.731
Common raven	0.088	0.068	0.145	0.053	0.668	0.506
Pacific-slope flycatcher	0.058	0.058	0.000	0.000	1.000	0.320
Western kingbird	0.021	0.021	0.000	0.000	1.000	0.320
Horned lark	0.455	0.171	0.456	0.364	0.003	0.998
Tree swallow	0.000	0.000	0.013	0.013	1.000	0.320
Cliff swallow	0.063	0.063	0.046	0.036	0.226	0.821
Mountain bluebird	0.000	0.000	0.081	0.051	1.578	0.117
Northern mockingbird	0.082	0.082	0.000	0.000	1.000	0.320
Loggerhead shrike	0.066	0.052	0.438	0.185	1.918	0.058
European starling	1.704	0.466	3.235	0.770	1.713	0.090
Sparrow spp.	0.000	0.000	0.044	0.044	1.000	0.320
Savanna sparrow	0.073	0.073	0.000	0.000	1.000	0.320
Western meadowlark	1.964	0.526	3.817	0.693	2.070	0.041
Blackbird spp.	0.000	0.000	0.713	0.488	1.460	0.147
Red-winged blackbird	0.505	0.223	0.330	0.148	0.686	0.494
Tricolored blackbird	0.030	0.030	0.000	0.000	1.000	0.320
Brewer's blackbird	0.246	0.142	0.226	0.120	1.000	0.320
Brown-headed cowbird	0.058	0.058	0.000	0.000	1.000	0.320
House finch	0.693	0.331	0.000	0.000	2.090	0.039
Cockatiel	0.000	0.000	0.068	0.068	1.000	0.320
Unidentified bird spp.	0.450	0.170	0.269	0.127	2.109	0.037
Songbird spp.	0.526	0.233	1.184	0.372	1.560	0.122
Medium nonraptor spp.	0.000	0.000	0.199	0.090	2.214	0.029
Large nonraptor spp.	0.000	0.000	0.125	0.073	1.708	0.090
Bats	0.115	0.073	0.263	0.172	0.79	0.433
Target raptor species	2.445	0.381	4.430	0.538	3.13	0.002
Total raptors	2.583	0.380	4.786	0.537	3.48	0.001
Total birds	14.220	1.542	21.627	2.079	3.00	0.003

[a] See Appendix for scientific names.

birds (Table 5). Adjusted fatality rate of bats increased from zero at the old vertical-axis turbines to 16.4/year at the new, repowered turbines, but this difference was not significant, probably due to small sample sizes.

Compared to concurrently operating old-generation turbines during 2005–2007, adjusted fatality rates in the repowered Diablo Winds turbines were lower by 64% for red-tailed hawks, 92% for American kestrel, 92% for rock

Table 5. Fatality rates caused by Diablo Winds Energy Project in the Altamont Pass Wind Resource Area, California, USA, 1) before (1998–2001) and after (2005–2007) repowering from Flowind 150-kilowatt (kW) and 250-kW vertical-axis turbines to Vestas 660-kW turbines, using 2-tailed paired-sample *t*-tests (df = 35), and 2) between repowered wind turbines in the Diablo Winds Energy Project and old-generation wind turbines operating concurrently in 2005–2007, using 2-tailed independent samples *t*-tests (df = 344).

	Adjusted fatality-rates (deaths/megawatt/yr)						*P*-value	
	Before repowering 1998–2002		After repowering 2005–2007		Old generation turbines 2005–2007		Before to after repowering at Diablo Winds	Diablo Winds to old turbines after repowering
Species[a]	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE		
Turkey vulture	0.000	0.000	0.016	0.016	0.018	0.013	0.337[c]	0.970[b]
Golden eagle	0.000	0.000	0.016	0.016	0.118	0.029	0.337[c]	0.489[b]
Red-tailed hawk	0.111	0.066	0.247	0.096	0.692	0.081	0.238[b]	0.001[c]
American kestrel	0.076	0.076	0.066	0.066	0.779	0.131	0.934[b]	0.000[c]
Burrowing owl	1.809	0.730	1.429	0.431	1.873	0.261	0.719	0.737[b]
Barn owl	0.208	0.186	0.012	0.012	0.257	0.048	0.444[b]	0.314[b]
Pied-billed grebe	0.000	0.000	0.268	0.268	0.000	0.000	0.337[c]	0.337[c]
Gull spp.	0.157	0.157	0.100	0.053	0.113	0.035	0.795[b]	0.940[b]
Mallard	0.519	0.426	0.033	0.033	0.122	0.063	0.410[b]	0.781[b]
Cliff swallow	0.487	0.403	0.000	0.000	0.036	0.024	0.383[b]	0.766[b]
Loggerhead shrike	0.000	0.000	0.179	0.121	0.321	0.110	0.165[c]	0.799[b]
European starling	0.628	0.319	0.604	0.361	3.317	0.453	0.963[b]	0.238[b]
Horned lark	0.085	0.085	0.090	0.090	0.515	0.178	0.971[b]	0.637[b]
Rock pigeon	0.089	0.071	0.114	0.072	1.468	0.235	0.820[b]	0.000[c]
Mourning dove	0.000	0.000	0.157	0.107	0.574	0.131	0.147[c]	0.532[b]
Hammond's flycatcher	0.000	0.000	0.090	0.090	0.005	0.005	0.337[c]	0.366[c]
Western meadowlark	2.249	0.945	1.747	0.597	3.135	0.338	0.715[b]	0.409[b]
Blackbird spp.	0.325	0.325	0.000	0.000	0.381	0.174	0.470[b]	0.666[b]
Brewer's blackbird	0.330	0.330	0.000	0.000	0.357	0.119	0.470[b]	0.554[b]
House finch	0.450	0.346	0.090	0.090	0.000	0.000	0.455[b]	0.337[c]
Unidentified bird	0.000	0.000	0.411	0.275	0.299	0.108	0.161[c]	0.839[b]
Bats	0.000	0.000	0.783	0.548	0.087	0.057	0.179[c]	0.231[c]
Target species	1.996	0.763	1.758	0.393	3.462	0.309	0.784[c]	0.002[c]
Total raptors	2.204	0.762	1.786	0.388	3.737	0.316	0.628[c]	0.000[c]
Total birds	7.523	1.564	5.669	1.291	14.380	1.054	0.432[b]	0.000[c]

[a] See Appendix for scientific names.
[b] Assumed equal variances, because $P > 0.05$ in Levene's Test for Equality of Variances.
[c] Assumed unequal variances, because $P \leq 0.05$ in Levene's Test for Equality of Variances.

pigeon, 49% for all target raptors, 54% for all raptors, and 66% for all birds (Table 5). Though not significant, mean adjusted fatality estimates were lower by 87% for golden eagles, 24% for burrowing owls, 95% for barn owl, 83% for horned lark (*Eremophila alpestris actia*), 73% for mourning dove (*Zenaida macroura*), 44% for loggerhead shrike (*Lanius ludovicianus*), and 44% for western meadowlark. Adjusted fatality rate of bats was nearly 800% greater at repowered turbines compared to concurrently operated old-generation turbines, but this large difference was not significant, probably due to sample sizes.

DISCUSSION

The APWRA-wide estimates of adjusted fatality rates did not lessen since 1998–2003, even though 200 100-kW Vestas turbines did not operate over 16 months of the 2005–2007 monitoring period and most APWRA turbines were shut down for 2 months of each winter. Among the mutually surveyed old-generation wind turbines, adjusted fatality rates increased significantly for the target raptors, all raptors, and all birds. We propose 4 alternative hypotheses for why the Avian Protection Program has not yet reduced fatality rates.

First, our data suggest that fatality rates might have increased if wind power generation increased within the APWRA. However, wind-power generation data from 1999 and 2006 did not support this hypothesis, assuming power generation during these years represented the corresponding fatality monitoring periods. We related monthly power-generation data maintained by the California Energy Commission to our estimated annual adjusted fatality rates for the subset of old-generation wind turbines that we searched during both monitoring periods. The capacity factor (annual MW-hr/MW of rated capacity, expressed as %) of the APWRA's old generation turbines actually decreased between 1999 and 2006 from 16.7% to 13.3%. Thus, annual deaths per gigawatt (GW)-hour increased for most species, and it increased from 1.71 raptors/GW-hour to 3.98 raptors/GW-hour (133%) and from 9.42 birds to 17.92 birds/GW-hour (90%). Fatality rates increased although power generation from old-generation turbines decreased.

Second, we suggest that increases in fatality rates may have tracked increases in avian abundance in the APWRA. We were unable to test whether relative abundance increased because utilization data remained unprepared to account for methodological differences between monitoring periods, especially the maximum distance from the observer at which birds were recorded.

Third, we suggest that fatality rates increased due to methodological bias. Our adjustments for scavenger removal were intended to account for the difference in average search interval between the 1998–2002 and 2005–2007 monitoring periods, but we lack an independent check on whether the adjustment was sufficient. It is possible that fatality rates only appeared to increase due to the shorter search interval in 2005–2007.

Fourth, we suggest that fatality rates might have increased due to inadequate or even counterproductive implementation of the Avian Protection Program (Table 2). The wind companies delayed relocating hazardous turbines until late 2007. Wind companies left vacant lattice towers at ends of rows as flight diverters, but this practice may have caused more raptor fatalities because raptors readily perched on vacant towers, which were adjacent to operating turbines. We often observed perched raptors flush as other territorial or predatory birds approached, and perched raptors often altered flight patterns of smaller raptors. Increases in these types of interactions could have led to increased collisions. Vacant towers and broken turbines were also left within turbine rows, which created gaps amongst functional turbines, and these gaps might have encouraged raptors to attempt row crossings where other raptors were perched. Alameda County required a winter shut-down that reactivated half the turbines when red-tailed hawks peaked in number and were likely habituated to shut-down turbines. For a company with 20% of the APWRA's turbines, the County waived the required increase in the duration of its winter shut-down. The blade-painting experiment of Altamont Winds, Inc. (Oakland, CA) was too small in scope to be noticed in APWRA-wide estimates of fatality rates. Finally, the year-long delay in forming the SRC also delayed scientific input on these measures.

The Diablo Winds repowering project did not reduce fatality rates compared to replaced turbines, but probably because the replaced turbines were largely defunct by the time we monitored them for fatalities in 1998–2001. We lack sufficient resolution in the wind-energy generation data at the California Energy Commission to test whether the Flowind vertical-axis turbines were declining in power output before replacement, but we recall that they rarely operated during our fatality searches. We suspect that starting with Diablo Winds, the least productive wind turbines are those selected for repowering, resulting in small if any reductions in fatality rates within the repowering project. Perhaps more relevant than comparing to fatality rates caused by a group of turbines already phased out of existence, we found substantially lower fatality rates caused by the new Diablo Winds turbines compared to concurrently operating old-generation turbines during 2005–2007. Fatality rates seemed lower yet after factoring in the improved capacity factor of the repowered turbines, which was 36.9% at Diablo Winds in 2006 compared with 13.3% at concurrently operating old-generation turbines. Fatalities per GW-hour at the repowered Diablo Winds project were lower than at the concurrently operating old-generation turbines by 94% for golden eagle, 84% for red-tailed hawk, 96% for American kestrel, 67% for burrowing owl, 78% for target raptors, 80% for all raptors, and 85% for all birds. Repowering the entire APWRA would likely reduce fatality rates a great deal, especially if considered on a power generation basis and if carefully done by locating new turbines where they pose the least hazard (Smallwood and Neher 2005, Smallwood et al. 2009). The improved capacity factor of new-generation turbines could also offset much of the nameplate capacity in the APWRA, so assuming the 36.9% capacity factor would apply throughout the APWRA, the same power generation could be achieved by 209 MW of nameplate capacity instead of the permitted 580 MW operating in the APWRA today. This capacity would include 209–317 wind turbines, assuming the turbines would range in size from 660 kW to 1 MW or 4% to 6% of the approximately 5,000 turbines that operated in 2005–2007. Turbine operations could also be restricted to times of day, seasons, or specific wind conditions to further reduce fatality rates.

A possible downside to repowering, however, may be increased bat fatalities caused by wind turbines. Extrapolating the mean adjusted bat fatality rate from Diablo Winds to a completely repowered APWRA, about 454 bat fatalities/year might result, but using more realistic scavenger-removal and searcher-detection rates could increase this number to thousands of bats. Bat fatalities in the APWRA need additional, focused research.

MANAGEMENT IMPLICATIONS

To reduce avian fatality rates caused by wind turbines in the Altamont Pass, the old-generation wind turbines should be carefully repowered as soon as possible because estimated mean annual fatalities could be reduced 54% for all raptors and 65% for all birds, while adding about 1,000 GW-hours of wind energy annually due to the nearly 3-fold increase in the capacity factor of new-generation turbines. Alternatively, the nameplate capacity of the repowered APWRA could be restricted to 209 MW to meet current energy generation levels, thereby reducing estimated mean annual fatalities 83% for all raptors and 87% for all birds. To lessen fatality rates before repowering, Alameda County would need to enforce permit conditions and require implementation of SRC recommendations, including a 4-month winter shut-down of all wind turbines, removal or careful relocation of the most hazardous turbines, and removal of vacant towers and broken turbines. Finally, State and Federal regulatory agencies could help reduce fatality rates by enforcing the MBTA and other environmental laws.

ACKNOWLEDGMENTS

We thank J. Camp, A. Chatfield, A. Carter, S. Standish, N. Quiros, L. Nason, H. Snively, A. Rex, A. Grant, T. Poitras, A. Hines, and S. Menzel for data collection. We thank W. Erickson and R. Anderson for sampling design and early management of the monitoring crew. We thank B. Latta, R. Culver, S. Rivera, and the wind companies for logistical support and the Alameda County SRC members S. Orloff, J. Burger, J. Estep, and J. Yee for guidance on project design and implementation. Our paper benefitted greatly from reviews by M. Morrison, an anonymous reviewer, and Associate Editor M. J. Bechard.

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Associate Editor: Bechard.

Appendix. Avian and bat species recorded as fatalities or mortally wounded at wind turbines of the Altamont Pass Wind Resource Area (APWRA), California, USA, from January 1989 through October 2007, including estimates of wind turbine–caused fatality rates from 2 time periods of scientific monitoring. We denote status as FE = Federal Endangered, FT = Federal Threatened, CE = California Endangered, CT = California Threatened, CFP = California Fully Protected, CSC = California Department of Fish and Game listing of California Species of Concern. California Fish and Game Code 3503.5 protected all raptors, and the Migratory Bird Treaty Act protected all species in the table except exotic species and bats. We revised fatality estimates for 1998–2003 from those of Smallwood and Thelander (2008) by including the wind companies' Wildlife Response and Reporting System (WRRS) data and using similar assumptions to those of the 2005–2007 monitoring period. The 2005–2007 annual fatality estimates were sums of estimated annual fatalities from separate monitoring efforts, including from East Bay Regional Park District, Diablo Winds Energy Project, and a stratified random sample of turbines. LCL and UCL denote lower and upper confidence limits, respectively.

				Estimated APWRA-wide annual fatalities (80% CI)					
				1998–2003			2005–2007		
Species or taxonomic group	Species name	Status	Recorded deaths 1989–2007	Total	LCL	UCL	Total	LCL	UCL
Turkey vulture	*Cathartes aura*		32	2.5	0.6	4.5	10.2	0.8	19.6
Golden eagle	*Aquila chrysaetos*	CSC, CFP	495	55.3	24.3	86.3	64.7	42.3	87.0
Cooper's hawk	*Accipiter cooperii*	CSC	1						
Red-tailed hawk	*Buteo jamaicensis*		1250	177.3	114.5	240.2	391.7	302.8	480.6
Ferruginous hawk	*Buteo regalis*	CSC	13	0.0	0.0	0.0	4.0	−1.0	8.9
Swainson's hawk	*Buteo swainsoni*	CT	2	0.0	0.0	0.0	0.5	−0.2	1.2
Rough-legged hawk	*Buteo lagopus*		1						
Red-shouldered hawk	*Buteo lineatus*		1	0.0	0.0	0.0	0.3	−0.1	0.7
Buteo spp.	*Buteo* spp.		45	0.0	0.0	0.0	16.6	6.4	26.9
Northern harrier	*Circus cyaeneus*	CSC	10	0.7	0.1	1.2	3.3	0.7	5.9
White-tailed kite	*Elanus leucurus*	CFP	3	0.0	0.0	0.0	0.4	−0.1	0.8
Hawk spp.			8	0.0	0.0	0.0	1.0	−0.3	2.2
Peregrine falcon	*Falco peregrinus*	CE, CFP	2						
Prairie falcon	*Falco mexicanus*	CSC	8	1.1	0.2	2.0	1.3	0.3	2.4
American kestrel	*Falco sparverius*		217	731.2	286.0	1,176.3	439.9	285.3	594.5
Falcon spp.	*Falco* spp.		2						
Burrowing owl	*Athene cunicularia*	CSC	287	858.3	241.2	1,475.4	1,112.4	736.8	1,487.9
Great horned owl	*Bubo virginianus*		91	7.3	3.3	11.2	31.8	18.6	45.0
Long-eared owl	*Asio otus wilsonianus*	CSC	2						
Barn owl	*Tyto alba*		286	46.0	19.2	72.7	150.2	103.6	196.8
Owl spp.			3	0.0	0.0	0.0	0.1	0.0	0.3
Large raptor spp.			4	0.0	0.0	0.0	1.3	0.1	2.6
Raptor spp.			66	0.2	−0.1	0.5	2.3	0.2	4.4
Common poorwill	*Phalaenoptilus nuttallii*		1						
Brown pelican	*Pelicanus occidentalis*	FE, CE	1						
Double-crested cormorant	*Phalacrocorax auritus*	CSC	2	2.1	−0.7	4.8	0.0	0.0	0.0
Pied-billed grebe	*Podilymbus podiceps*		1	0.0	0.0	0.0	5.4	−2.3	13.2
Black-crowned night heron	*Nycticorax nycticorax*	CSA	3	1.1	0.0	2.2	0.0	0.0	0.0
Great blue heron	*Ardea herodius*		9	0.0	0.0	0.0	0.7	−0.2	1.7
Great egret	*Ardea alba*		2	0.0	0.0	0.0	28.1	−9.1	65.3

Appendix. Continued.

Species or taxonomic group	Species name	Status	Recorded deaths 1989–2007	Estimated APWRA-wide annual fatalities (80% CI)					
				1998–2003			2005–2007		
				Total	LCL	UCL	Total	LCL	UCL
Cattle egret	*Bubulcus ibis*	Exotic	1	3.1	−1.1	7.3	0.0	0.0	0.0
Sandhill crane	*Grus canadensis*	CT	1	0.0	0.0	0.0	1.5	−0.5	3.5
Long-billed curlew[a]	*Numenius americanus*	CSC	3						
Black-necked stilt	*Himantopus mexicanus*		1	0.0	0.0	0.0	23.0	−11.2	57.1
American avocet	*Recurvirostra americana*		4	6.7	−0.9	14.3	0.0	0.0	0.0
Lesser yellowlegs	*Tringa flavipes*		1	1.9	−1.1	4.9	0.0	0.0	0.0
Killdeer	*Charadrius vociverus*		4	0.0	0.0	0.0	6.3	−1.3	13.9
Ring-billed gull	*Larus delawarensis*		6	8.6	1.2	16.0	0.0	0.0	0.0
California gull	*Larus californicus*	CSC	21	8.8	2.8	14.8	6.4	−2.1	14.8
Herring gull	*Larus argentatus*		2						
Thayer's gull	*Larus thayeri*		1						
Mew gull	*Larus canus*		1						
Gull spp.	*Larus* spp.		85	109.2	38.0	180.4	65.0	31.0	98.9
Mallard	*Anas platyrhynchos*		67	55.6	13.0	98.2	67.5	17.3	117.7
Ring-necked duck	*Aythya collaris*		1	4.2	−1.5	9.9	0.0	0.0	0.0
Duck spp.			5	0.0	0.0	0.0	9.8	1.8	17.7
Wild turkey	*Melleagris gallopavo*	exotic	3	1.5	−0.5	3.6	0.9	−0.3	2.1
Mourning dove	*Zenaida macroura*		77	468.0	−112.0	1047.9	313.2	59.3	567.1
Rock pigeon	*Columba livia*	exotic	731	324.9	197.8	452.1	2,292.5	1,266.6	3,318.3
Band-tailed pigeon	*Columba fasciata*		1						
Dove spp.			11	0.0	0.0	0.0	35.6	1.4	69.9
Northern flicker	*Colaptes auratus*		9	147.3	−116.9	411.5	15.3	−7.5	38.1
White-throated swift	*Aeronautes saxatalis*		3	0.0	0.0	0.0	40.9	−10.1	91.9
Vaux's swift	*Chaetura vauxi vauxi*		1						
Tree swallow	*Tachycineta bicolor*		1	0.0	0.0	0.0	2.3	−1.1	5.8
Violet-green swallow	*Tachycineta thalassina*		2	2.4	−1.4	6.2	0.0	0.0	0.0
Cliff swallow	*Hirundo pyrrhonota*		10	29.8	−4.6	64.3	27.0	−4.9	59.0
Loggerhead shrike	*Lanius ludovicianus*	CSC	29	122.8	−97.7	343.4	181.4	21.6	341.2
Northern shrike	*Lanius excubitor*		1						
European starling	*Sturnus vulgaris*	exotic	315	1,319.0	−712.7	3,350.7	1,882.9	421.5	3,344.4
Northern mockingbird	*Mimus polyglottos*		3	9.3	−5.5	24.0	9.3	−4.5	23.2
Swainson's thrush	*Catharus ustulatus*		1	0.0	0.0	0.0	8.4	−4.1	20.9
American robin	*Turdus migratorius*		1						
Horned lark	*Eremophila alpestris actia*	CSC	56	114.0	−24.9	252.9	292.5	34.5	550.5
American crow	*Corvus brachyrhynchos*		24	15.8	2.5	29.0	30.5	12.1	48.9
Common raven	*Corvus corax*		86	40.8	1.0	80.6	88.8	40.1	137.6
Scrub jay	*Aphelocoma californica*		3	0.0	0.0	0.0	0.9	−0.4	2.2
Corvid spp.			14						
Pacific-slope flycatcher	*Empidonax difficilis*		1	6.4	−3.8	16.6	0.0	0.0	0.0
Western kingbird	*Tyrannus verticalis*		1	2.5	−1.5	6.5	0.0	0.0	0.0
Hammond's flycatcher	*Empidonax hammondii*		2	0.0	0.0	0.0	4.7	−2.2	11.7
Say's phoebe	*Sayornis saya*		4	0.0	0.0	0.0	11.3	−5.5	28.0
Western tanager	*Piranga ludoviciana*		1	0.0	0.0	0.0	2.2	−1.1	5.5
American pipit	*Anthus rubescens*		2	0.0	0.0	0.0	3.3	−1.6	8.1
Bluebird spp.			3	0.0	0.0	0.0	51.0	−6.1	108.1
Mountain bluebird	*Sialia currucoides*		22	146.5	−117.7	410.8	33.8	2.6	65.1
Western bluebird	*Sialia mexicana*		5						
House wren	*Troglodytes aedon*		1	0.0	0.0	0.0	4.7	−2.3	11.7
Rock wren	*Salpinctes obsoletus*		2	0.0	0.0	0.0	8.9	−4.3	22.2
Yellow warbler	*Dendroica petechia*	CSC	1	3.6	−2.1	9.3	0.0	0.0	0.0
Sparrow spp.			3	0.0	0.0	0.0	7.8	−3.8	19.4
Townsend's warbler	*Dendroica townsendi*		1						
Orange-crowned warbler	*Vermivora celata*		1						
Fox sparrow	*Passerella iliaca*		1						
Savanna sparrow	*Passerculus sandwichensis*		2	33.0	−31.1	97.1	0.0	0.0	0.0
Lincoln sparrow	*Melospiza lincolnii*		1	0.0	0.0	0.0	2.9	−1.4	7.3
Western meadowlark	*Sturnella neglecta*		344	1,594.2	−796.5	3,984.9	1,761.7	411.2	3,112.3
Brewer's blackbird	*Euphagus cyanocephalus*		39	340.5	−249.7	930.7	193.8	26.1	361.4
Brown-headed cowbird	*Molothrus ater*		3	145.9	−151.8	443.6	28.8	−14.0	71.6
Red-winged blackbird	*Agelaius phoeniceus*		35	77.3	−3.1	157.7	139.6	20.2	259.1
Tricolored blackbird	*Agelaius tricolor*	CSC	1	3.9	−2.3	10.1	0.0	0.0	0.0

Appendix. Continued.

Species or taxonomic group	Species name	Status	Recorded deaths 1989–2007	Estimated APWRA-wide annual fatalities (80% CI)					
				1998–2003			2005–2007		
				Total	LCL	UCL	Total	LCL	UCL
Blackbird spp.			16	9.5	−5.7	24.8	210.5	10.4	410.6
House finch	*Carpodacus mexicanus*		23	99.9	−6.5	206.3	1.8	−0.8	4.4
House sparrow	*Passer domesticus*	exotic	1	46.5	−49.3	142.3	0.0	0.0	0.0
Cockatiel	*Leptolophus hollandicus*	exotic	2	3.0	−1.8	7.7	12.2	−5.9	30.4
Small nonraptors			120	74.7	−4.4	153.7	339.9	65.8	614.0
Medium, large nonraptors			91	0.0	0.0	0.0	122.6	47.0	198.3
Bird spp.			120	285.9	−168.8	740.6	169.5	18.0	321.0
Target raptor species			2,249	1,822.1	666.0	2,978.2	2,008.6	1,367.1	2,650.0
Total raptors			2,289	1,879.8	689.3	3,070.3	2,232.0	1,496.1	2,967.9
Total birds			5,283	7,549.9	−1,731.9	16,831.8	9,297.1	3,217.8	1,5376.4
Mexican free-tail bat	*Tadarida brasiliensis*		3						
Western red bat	*Lasiurus borealis teleotis*		2						
Hoary bat	*Lasiurus cinereus*		11						
Bat spp.			3						
Total bats			19	14.4	−3.5	32.3	68.4	−5.4	142.1

[a] Reportedly found by Orloff and Flannery (1992) but did not appear in WRRS data base.

EXHIBIT
10

Conservation Biology

Contributed Paper

Effects of development of wind energy and associated changes in land use on bird densities in upland areas

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Abstract: *Wind energy development is the most recent of many pressures on upland bird communities and their habitats. Studies of birds in relation to wind energy development have focused on effects of direct mortality, but the importance of indirect effects (e.g., displacement, habitat loss) on avian community diversity and stability is increasingly being recognized. We used a control-impact study in combination with a gradient design to assess the effects of wind farms on upland bird densities and on bird species grouped by habitat association (forest and open-habitat species). We conducted 506 point count surveys at 12 wind-farm and 12 control sites in Ireland during 2 breeding seasons (2012 and 2013). Total bird densities were lower at wind farms than at control sites, and the greatest differences occurred close to turbines. Densities of forest species were significantly lower within 100 m of turbines than at greater distances, and this difference was mediated by habitat modifications associated with wind-farm development. In particular, reductions in forest cover adjacent to turbines was linked to the observed decrease in densities of forest species. Open-habitat species' densities were lower at wind farms but were not related to distance from turbines and were negatively related to size of the wind farm. This suggests that, for these species, wind-farm effects may occur at a landscape scale. Our findings indicate that the scale and intensity of the displacement effects of wind farms on upland birds depends on bird species' habitat associations and that the observed effects are mediated by changes in land use associated with wind-farm construction. This highlights the importance of construction effects and siting of turbines, tracks, and other infrastructure in understanding the impacts of wind farms on biodiversity.*

Keywords: bird guilds, displacement, habitat modification, land-use change, uplands, wind farms, wind turbines

Efectos del Desarrollo de la Energía Eólica y los Cambios Asociados al Uso de Suelo sobre las Densidades de Aves en Tierras Altas

Resumen: *El desarrollo de la energía eólica es la más reciente de muchas presiones ejercidas sobre las comunidades de aves de tierras altas y sus hábitats. Los estudios sobre aves en relación con el desarrollo de la energía eólica se han enfocado en los efectos de la mortalidad directa, pero la importancia de los efectos indirectos (p. ej.: desplazamiento, pérdida de hábitat) sobre la diversidad y estabilidad de las comunidades aviares cada vez se reconoce más. Usamos un estudio de control-impacto combinado con un diseño de gradiente para evaluar los efectos de los campos eólicos sobre las densidades de aves de tierras altas y sobre las especies de aves agrupadas por asociación de hábitat (especies de bosque y de hábitat abierto). Realizamos 506 censos de conteo por puntos en 12 sitios de campos eólicos y 12 sitios control en Irlanda durante dos temporadas de reproducción (2012 y 2013). Las densidades de aves totales fueron más bajas en los campos eólicos que en los sitios control, con las diferencias más importantes ocurriendo cerca de las turbinas. Las densidades de las especies de bosque fueron significativamente más bajas a 100 m de las turbinas que a distancias mayores y esta diferencia estuvo mediada por modificaciones asociadas con el desarrollo de campos eólicos. De manera particular, las reducciones en la cobertura de bosque adyacente a las turbinas estuvieron vinculadas con la disminución observada en las densidades de las especies de bosque.*

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Article impact statement: *Wind farm effects on birds in upland areas are guild specific and mediated by changes in land use associated with wind farm construction.*
Paper submitted May 15, 2017; revised manuscript accepted July 23, 2018.

Conservation Biology, Volume 0, No. 0, 1–10

DOI: 10.1111/cobi.13239

Las densidades de las especies de hábitat abierto fueron más bajas en los campos eólicos pero no estuvieron relacionadas con la distancia a las turbinas y tuvieron una relación negativa con el tamaño del campo eólico. Lo anterior sugiere que, para estas especies, los efectos del campo eólico pueden ocurrir a la escala de paisaje. Nuestros hallazgos indican que la escala y la intensidad de los efectos de desplazamiento de los campos eólicos sobre las aves de tierras altas dependen de las asociaciones de hábitat de las especies de aves y que los efectos observados están mediados por cambios en el uso de suelo asociados con la construcción de campos eólicos. Esto remarca la importancia de los efectos de construcción y el sitiado de las turbinas, pistas y demás infraestructura en el entendimiento de los impactos que tienen los campos eólicos sobre la biodiversidad.

Palabras Clave: cambio de uso de suelo, campos eólicos, desplazamiento, gremios de aves, modificación de hábitat, tierras altas, turbinas de viento

摘要: 风能的开发是山地鸟类群落面临的许多压力中最近出现的一种。关于鸟类与风能开发有关的研究主要集中于其直接导致鸟类死亡的影响, 但人们也逐渐认识到其对鸟类群落多样性和稳定性的间接影响 (如被迫迁徙、生境丧失) 的重要性。我们用控制-影响研究, 结合梯度设计, 来评估风电场对山地鸟类密度和按生境相关性分类的鸟类物种 (森林和开放生境的物种) 的影响。我们在 *2012* 年和 *2013* 年的两个繁殖季对爱尔兰 *12* 个风电场和 *12* 个对照位点对 *506* 个样点进行计数调查。结果显示, 风电场的鸟类总密度比对照位点低, 且差异最大的位置在涡轮机附近。在涡轮机附近 *100* 米内森林鸟类的密度显著低于离涡轮机更远的位置, 这一差异受到风电场建设相关生境改造的调控。特别是与观察到的森林鸟类密度下降与涡轮机附近森林覆盖的减少有关。风电场开放生境的物种密度也较低, 但这与距离涡轮机的远近无关, 而与风电场的大小呈负相关。这说明风电场对这些物种的影响可能发生在景观尺度上。我们的结果表明, 风电场导致山地鸟类被迫迁徙的影响尺度和强度取决于物种的生境相关性, 观察到的影响是由风电场建设相关的土地利用变化介导的。这强调了涡轮机、轨道和其它基础设施的施工效应及选址对于理解风电场对生物多样性影响的重要性。 **【翻译: 胡怡思; 审校: 聂永刚】**

关键词: 鸟类同资源种团, 被迫迁徙, 生境改造, 土地利用变化, 山地, 风电场, 风力涡轮机

Introduction

In recent decades, development of wind energy has played a key role in efforts to mitigate climate change by reducing carbon emissions while meeting increasing energy demands. It is expected that by 2050, wind energy will provide 20% of global energy requirements (IPCC 2015). Although widely perceived as one of the most environmentally responsible and affordable energy sources, ongoing increases in development of wind energy have led to concerns about its potential environmental impacts (Leung & Yang 2012; Tabassum et al. 2014; Zwart et al. 2016). Large-scale installations can result in habitat loss and degradation, displacement of wildlife, and direct mortality of birds and bats (Kuvlesky et al. 2007; Pearce-Higgins et al. 2009; Northrup & Wittemyer 2013).

In many parts of the world, onshore wind farms are commonly built in areas with high elevation, sparse human populations, and relatively low levels of management and economic productivity. These areas are attractive for wind-energy development because they typically combine high wind yield with few economically competing land uses (Bright et al. 2008; Schuster et al. 2015). However, these upland areas are often also priority conservation areas with important bird assemblages, including generalists, upland specialists, and migratory birds. In Europe many of these bird species are of conservation concern; thus, their populations are sensitive to wind-farm development and expansion (e.g., Bright et al. 2008; Bonn et al. 2009; Wilson et al. 2017). Upland bird communities have been shaped by human activity, in particular habitat loss and degradation related to agricultural improvement, peat extraction, recreation, air pollution, and climate (Fielding & Haworth 1999; Pearce-Higgins et al. 2008). Because development of wind energy has been incentivized by policies aiming to reduce carbon emissions from energy production, its effects on upland birds can be regarded as an indirect consequence of climate change (Evans & Douglas 2014). The scale of wind-farm development in many upland areas has led to a growing demand for information on its potential impacts on birds to guide sustainable development of the wind energy sector (Katzner et al. 2013; Zwart et al. 2016).

Early studies of the effects of wind farms on birds most commonly assessed direct mortality associated with wind turbines (Leung & Yang 2012; Erickson et al. 2014; Smith & Dwyer 2016). Recently, the scope of studies has broadened to include assessments of secondary effects, such as disturbance and displacement, either through habitat loss or species avoidance of habitat (e.g., Pearce-Higgins et al. 2009; Astiaso Garcia et al. 2015; Shaffer & Buhl 2016). Research has also evaluated the impact of wind farms on a variety of bird breeding indices (e.g., Pearce-Higgins et al. 2012; Sansom et al. 2016; Rasran & Mammen 2017). Reviews on the displacement effect of wind farms on birds indicate that the existence and extent of impacts varies considerably across species, land cover, seasons, and geographic regions (e.g., Pearce-Higgins et al. 2009; Shaffer & Buhl 2016; Smith & Dwyer 2016). Despite this variability, the majority of studies have focused on a small number of endangered or charismatic species with already low abundances (e.g., De Lucas et al. 2008; Smith & Dwyer 2016). Although the displacement of key species can ultimately result in a shift in the structure of avian communities (Tabassum et al. 2014), there have been few publications on the impacts of wind farms at a multispecies scale. Furthermore, few studies take into account the interdependent effects of the presence of wind turbines and habitat modification or address ecosystem-level impacts of wind-energy development. Understanding whether, and to what extent, wind turbines affect bird communities as a whole is an essential step toward understanding the effects of wind farms at an ecosystem scale.

We designed an impact-control study to assess bird densities and changes in land use due to construction at a range of large, modern wind farms and paired control sites. By surveying points at a range of distances from turbines, we simultaneously assessed impact-gradient effects. We sought to compare bird densities between areas with and without a wind farm; determine the effects of distance from wind turbines and age and size of a wind farm on total bird densities; assess whether, and how, observed effects are related to changes to species groups with different habitat associations; and assess potential effects of changes in land use due to wind-farm development on total bird densities. Our study is one of the first to combine surveys of multiple wind farms and control sites with an impact-gradient approach to assess the effects of wind-energy development on upland birds in a multispecies context (review of studies in Shaffer and Buhl [2016]).

Methods

Survey Design

We surveyed 6 wind farms and 6 control sites in 2012 and a further 6 of each in 2013, all in upland habitats across Ireland. Irish uplands are characterized by a mosaic of open habitats (e.g., heath, bog, rough and improved grassland, scrub) and closed habitats (commercial forestry plantation and natural forests). To maximize the detection of effects, we selected large, modern wind farms with at least 8 turbines of similar design covering a broad geographical range (2–8 years since construction; 8–35 turbines with individual outputs of 850–2500 kW [Supporting Information]). For each wind-farm site, a control site was selected within 12 km in an area of similar size, habitat composition, and topography but without wind-farm development. The similarity between wind-farm and control-site habitat composition (preconstruction) was assessed by visual inspection of satellite images and topographical maps. To avoid confounding effects of yearly variations in bird densities, each wind farm and its corresponding control site were surveyed during the same breeding season.

At each wind farm, 27 survey points were selected at increasing distances from the nearest turbine (9 survey points within 100 m of turbines, 6 at 100–400 m, 6 at 400–700 m, and 6 at 700–1000 m). To avoid any confounding effects of multiple turbines, points farther than 100 m from individual turbines were selected only outside of the minimum polygon containing all turbine 100-m buffers. Within each distance band, survey points were selected to represent the range of habitats and human-made structures present within that band. All points were at least 200 m from the nearest neighboring point to avoid multiple detections of individual birds.

For each survey point at a wind farm, a matching survey point with similar habitat characteristics and elevation was selected at the corresponding control site. Our aim was to assess the overall effect of wind-farm development, including the presence of turbines and the effect of changes in land use associated with wind-farm construction. For this reason, habitat composition (percent cover, based on aerial photographs) at control points was matched with that of the survey point at the wind farm prior to construction (habitat types: pre-thicket forest, closed canopy, clearfell, grassland, scrub, peatland, or human altered). This was done with the aid of aerial photographs taken prior to wind-farm construction. All pairs of wind farm and control points were selected to contain the same habitat types in as similar percentage cover as possible (±5%). By matching control-point habitats with those of wind-farm points prior to construction we ensured that land-use and habitat changes due to wind-farm development could be assessed. As a result, we expected that habitat differences would be greatest for points located closest to wind farms, where habitats would be most affected by construction. To account for variation in bird densities due to elevation, control survey points were also selected to match the elevation of their corresponding wind-farm point.

Many upland bird species in Ireland are rare and occur at relatively low abundances. Because this could affect the observed trends in total bird densities, we also carried out an analysis of densities of the most common bird species. Because of the configuration of upland habitats in Ireland, the most common bird species are associated with either forest or open habitats. By analyzing densities of forest birds and open-habitat birds, we were able to study the effects of land-use changes associated with wind farms on bird groups linked to specific habitats.

Bird and Habitat Surveys

Breeding birds were surveyed using the point-count method following Bibby et al. (2000). Surveys were conducted on days without persistent rain or strong wind (<20 km/hour) during the breeding seasons (April to

June) and in the mornings (from 1 hour after dawn until noon). Each point was visited once for 5 minutes, during which time all birds detected by sight or sound within a 100-m radius were recorded and their distance from the observer noted. All data collection was carried out under license issued by the National Parks & Wildlife Service in Ireland in accordance with the Wildlife Act 1976. Flying birds were excluded from the data analysis unless they were actively foraging or singing. Distance estimates were made by experienced observers aided by scaled aerial photos. Because time of day or season can affect bird densities, point-count pairs (wind farm and control) were surveyed in succession. If this was not possible, they were visited within the next 2 days at the same time of day and under similar weather conditions. Distance software version 5.0 (Thomas et al. 2010) was used to derive species densities from field observations. For further details on survey methods and density estimate calculations, see Supporting Information.

Survey-point bird densities were calculated for individual species and summed to calculate total bird densities. Using information on avian ecology and habitat associations in Ireland (Nairn & O'Halloran 2012), we also classified the most commonly occurring species in our study as either forest species or open-habitat species. Forest species included Great Tit (*Parus major*), Coal Tit (*Periparus ater*), Chaffinch (*Fringilla coelebs*), and Goldcrest (*Regulus regulus*). Open-habitat species included Meadow Pipit (*Anthus pratensis*), Skylark (*Alauda arvensis*), and Wheatear (*Oenanthe oenanthe*).

Once the bird survey at each point was completed, habitats within the 100-m survey radius were categorized as pre-thicket forest, closed canopy, clearfell, grassland, scrub, peatland, or human altered (e.g., bare ground, buildings, tracks providing access for forestry operations or wind farms). Percent cover of habitats, point-count elevation, and distance from nearest wind turbine were calculated using ArcGIS 10 software (Environmental Science Research Institute, Redlands, California).

Of the 648 designated point counts, it was not possible to carry out surveys at 71 points due to land-access constraints. To maintain the paired design, their corresponding survey-point pairs were also excluded from analysis. This resulted in analysis of 506 survey points (253 points at wind farms, 253 points at control sites). The final distribution of wind-farm points was 68 within 100 m of the nearest turbine; 70 from 100 to 400 m; 56 from 400 to 700 m; and 59 from 700 to 1000 m.

Data Analyses

To assess how different factors affected bird densities, we used generalized linear mixed models (GLMMs) with a Gaussian distribution and identity link functions (Zuur et al. 2013). We followed a 3-step process to test the effects of wind-energy development on bird densities. First, we built a base model explaining total bird densities (i.e., density of all species combined) based on environmental factors (percent cover of each habitat type and elevation in meters) and retaining only significant variables (model A). We then added a categorical variable with 2 levels (wind farm or control) to this model to test the effect of wind-farm development on total bird densities (model B). Finally, we used a subset of data from wind-farm sites only to test the effects of distance to turbine (meters), age of wind farm (years), and size (number of turbines as a proxy for size) on total bird densities, on forest bird densities, and on open-habitat bird densities (models C). Thus, models A and B included data from all survey points ($n = 506$), whereas model C included data from wind-farm survey points only ($n = 253$). To control for site-specific patterns, we included site as a random factor in all models (factor with 12 levels, 1 for each wind-farm and control-site pair). To control for non-independence of survey-point pairs, pair was included as a random effect nested within site for models A and B. Spearman correlation coefficients were calculated for all variable pairs. All variables included in analyses had values of $|r| < 0.5$.

Preliminary analysis revealed that the effects of wind farms on habitat were greatest closest to wind turbines. Therefore, to further analyze the spatial nature of any effects, we calculated total, forest, and open-habitat bird densities at wind-farm points at increasing distance bands from turbines (0–100 m, 100–400 m, 400–700 m, and 700–1000 m) and compared them with the densities of their matching control points with Wilcoxon signed-rank tests. To detect differences in habitats between matched points that could be attributed to wind-farm development (habitats at control points were matched to those at wind-farm points prior to construction), we performed similar analyses comparing percentage of each habitat type between wind-farm points and their matched control points for each of the distance bands. All statistical analyses were performed using R version 3.4.3 (www.r-project.org). The GLMM analyses were performed with R packages lme4 and nlme.

Results

Fifty-six bird species and 3715 individual birds were recorded. Thirty-six percent of the species recorded ($n = 20$) are of conservation concern in Ireland at present (Colhoun & Cummins 2013). Mean densities across all sites were 2.99 birds/ha, with 0.99 forest birds/ha and 0.47 open-habitat birds/ha. At wind farms, mean densities were 2.80 birds/ha, 0.93 forest birds/ha, and 0.41 open-habitat birds/ha. At control sites, mean densities were 3.19 birds/ha, 1.04 forest birds/ha, and 0.52 open-habitat birds/ha. For a list of species recorded, their conservation statuses, and densities see Supporting Information.

Table 1. Summary of environmental effects on total bird densities at wind-farm and control sites (model A).*

Factor	Estimate (SE)	t	p
Intercept	5.677 (0.552)	10.29	<0.001
Closed canopy	0.024 (0.003)	7.08	<0.001
Pre-thicket	0.009 (0.004)	2.46	0.012
Peatland	−0.012 (0.003)	−4.01	<0.001
Elevation	−0.010 (0.001)	−5.74	<0.001

Predicted total bird densities (birds/ha) at individual point counts (n= 506) at 12 wind farm and 12 control sites modeled as a function of environmental factors (land-cover type and elevation). Point-count pair nested within site was included as a random factor.

Table 2. Summary of effects of wind-farm development on total bird densities at wind farm and control sites (model B).*

Factor	Estimate (SE)	t	p
Intercept	5.822 (0.555)	10.50	<0.001
Closed canopy	0.024 (0.003)	6.84	<0.001
Pre-thicket	0.008 (0.004)	2.25	0.024
Peatland	−0.012 (0.003)	−4.20	<0.001
Elevation	−0.010 (0.002)	−5.62	<0.001
Wind farm present	−0.313 (0.148)	−2.11	0.035

Predicted bird densities (birds/ha) at individual point counts (n = 506) at 12 wind farm and 12 control sites modeled as a function of different land-cover types (percent), elevation (meters), and presence or absence of wind farms. Point-count pair nested within site was included as a random factor.

Bird densities at all survey points (wind farm and matching control) were influenced by different habitat covers and elevation (model A, Table 1). However, point counts at wind farm sites showed significantly lower bird densities than point counts at control sites (model B, Table 2).

Tests of characteristics specific to wind farms revealed different effects on total, forest, and open-habitat bird densities (C models, Table 3). Distance to turbine was significantly and positively related to total bird densities, indicating an increase in densities at increasing distances from turbines. Densities of forest birds showed a similar significant positive effect of distance to turbine. However, for open-habitat birds, only size of the wind farm was significant; large wind farms held lower densities of open-habitat birds.

Differences in total bird densities were greatest for paired wind-farm and control points that were closest to wind turbines (Fig. 1a). When assessed by distance bands, these differences were significant between wind-farm points within 100 m of turbines and their paired control points ($z = 1043.5, p < 0.001$) (Fig. 1b) but not for other distance bands. Densities of forest birds were significantly lower at wind-farm points within 100 m of wind turbines than at matching control points ($z = 553.5$, $p = 0.009$) (Fig. 1c) but not for other distance bands. Densities of open-habitat bird species were significantly lower at wind-farm sites than control sites ($z = 2910.0$, $p = 0.008$), but this difference was not significant for any specific distance band (Fig. 1d).

Comparison of habitat composition at wind-farm and control points highlighted significant differences for 3 habitat types attributed to construction effects: human-altered (bare ground, tracks, and buildings), clearfelled forest, and closed canopy forest (Fig. 2). Human-altered habitats occurred more frequently at wind-farm points ($z = 4126.0$, $p < 0.001$) (Fig. 2a); differences were significant up to 700 m from turbines. Likewise, clearfelled forest occurred more frequently at wind-farm points ($z = 492.0$, $p = 0.039$) (Fig. 2b); differences were significant within 100 m from turbines. Closed canopy forest was less abundant at wind-farm points within 100 m of turbines than at their corresponding control points ($z = 636.5, p = 0.020$) (Fig. 2c).

Discussion

Total bird densities were lower at wind-farm sites than at control sites without wind-farm development. Because wind farms were generally located at high elevations, elevation decreased and bird densities increased at points farther from turbines and at matched control points (positive slope of both lines in Fig. 1a). However, bird densities close to wind turbines were lower than at matching control points, and we recorded a higher rate of elevation-related increase at wind-farm than at control sites (lower y-intercept and steeper slope of wind-farm average density represented by the dark grey line in Fig. 1a). This indicates a gradient effect of wind farms on bird densities. Maximum differences in bird densities were recorded between wind-farm points within 100 m of turbines and their corresponding control point pairs (Fig. 1b). These findings are consistent with other studies showing the displacement of birds in areas within a few hundred meters of turbines (Pearce-Higgins et al. 2009; Stevens et al. 2013; Sansom et al. 2016; Shaffer & Buhl 2016). The magnitude of these displacement effects are shown by model estimate values indicating that total bird densities were 0.313 birds/ha (SE 0.148) lower at wind farms than control sites (Table 2). At wind-farm sites, total densities increased by 0.001 birds/ha/m (SE 0.000) (or 1.3 birds/ha/km [SE 0.4]) from a wind turbine (Table 3). Although these values may seem low, in the context of upland bird densities (e.g., mean of 2.99 birds/ha in our study) changes of 0.3–1.3 birds/ha can have important effects at both bird species population and community scales.

Densities of forest species were lower at wind farms than at control sites; distance to turbine significantly explained this observed difference. Specifically, points within 100 m of wind turbines had significantly lower densities of forest species than paired control points. In contrast, densities of open-habitat species were lower

Table 3. Summary of effects of wind-farm development on total, forest, and open-habitat bird densities at wind-farm sites (models C).*

Response variable	*Factor*	*Estimate (SE)*	*z*	*p*
Total species density (birds/ha)	intercept	4.966 (0.988)	5.03	0.002
	closed canopy	0.022 (0.004)	5.31	<0.001
	peatland	−0.015 (0.003)	−4.73	<0.001
	elevation	−0.007 (0.003)	−2.72	0.006
	distance	0.001 (0.000)	3.26	0.001
	age	−0.035 (0.084)	−0.41	0.681
	size	−0.014 (0.012)	−1.14	0.254
Forest species density (birds/ha)	intercept	0.770 (0.201)	3.83	<0.001
	closed canopy	0.018 (0.003)	7.00	<0.001
	peatland	−0.006 (0.002)	−2.94	0.003
	distance	0.001 (0.000)	3.33	0.001
	age	−0.030 (0.030)	−1.01	0.315
	size	−0.005 (0.004)	−1.25	0.213
Open-habitat species density (birds/ha)	intercept	−0.324 (0.272)	−1.19	0.234
	closed canopy	−0.003 (0.002)	−2.03	0.043
	grassland	0.005 (0.001)	3.78	<0.001
	peatland	0.007 (0.001)	5.51	<0.001
	elevation	0.002 (0.001)	2.61	0.009
	distance	0.001 (0.000)	0.91	0.365
	age	0.010 (0.016)	0.55	0.581
	size	−0.007 (0.002)	−3.11	0.002

Predicted total, forest, and open-habitat bird densities (birds/ha) at individual point counts (n = 253) at 12 wind farms modeled as a function of different land-cover types (percent), elevation (meters), distance to turbine (meters), and age (years) and size of wind farm (number of turbines). Site was included as a random factor.

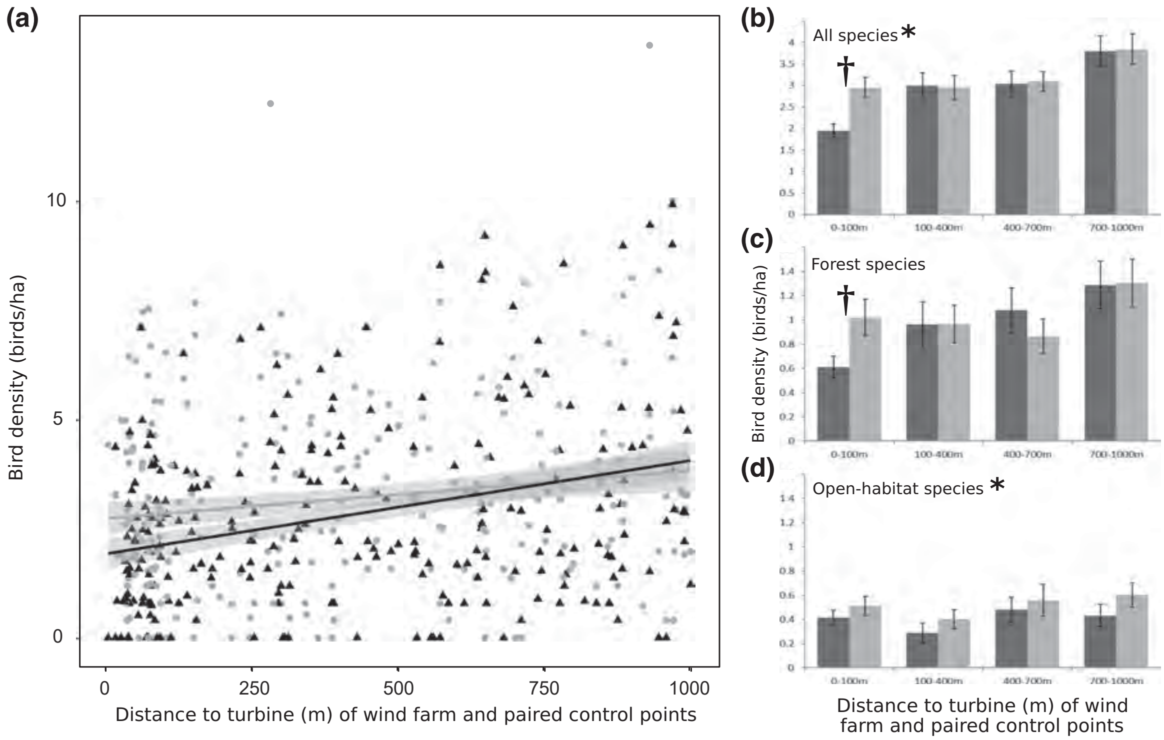

Figure 1. Bird densities recorded at 506 point counts at 12 wind farms (black) and 12 control sites (grey) in 2012 and 2013: (a) total bird densities at wind-farm point counts (triangles) and control point counts (circles) (lines, means; shading, 95% CI); (b) mean (SE) total bird densities in each distance band; (c) mean (SE) densities of forest bird species in each distance band; (d) mean (SE) density of open-habitat bird species in each distance band. Control point values are represented at the distance of their corresponding wind farm point pair (, statistical significance for that group independent of distance; †, statistical significance for that distance band).*

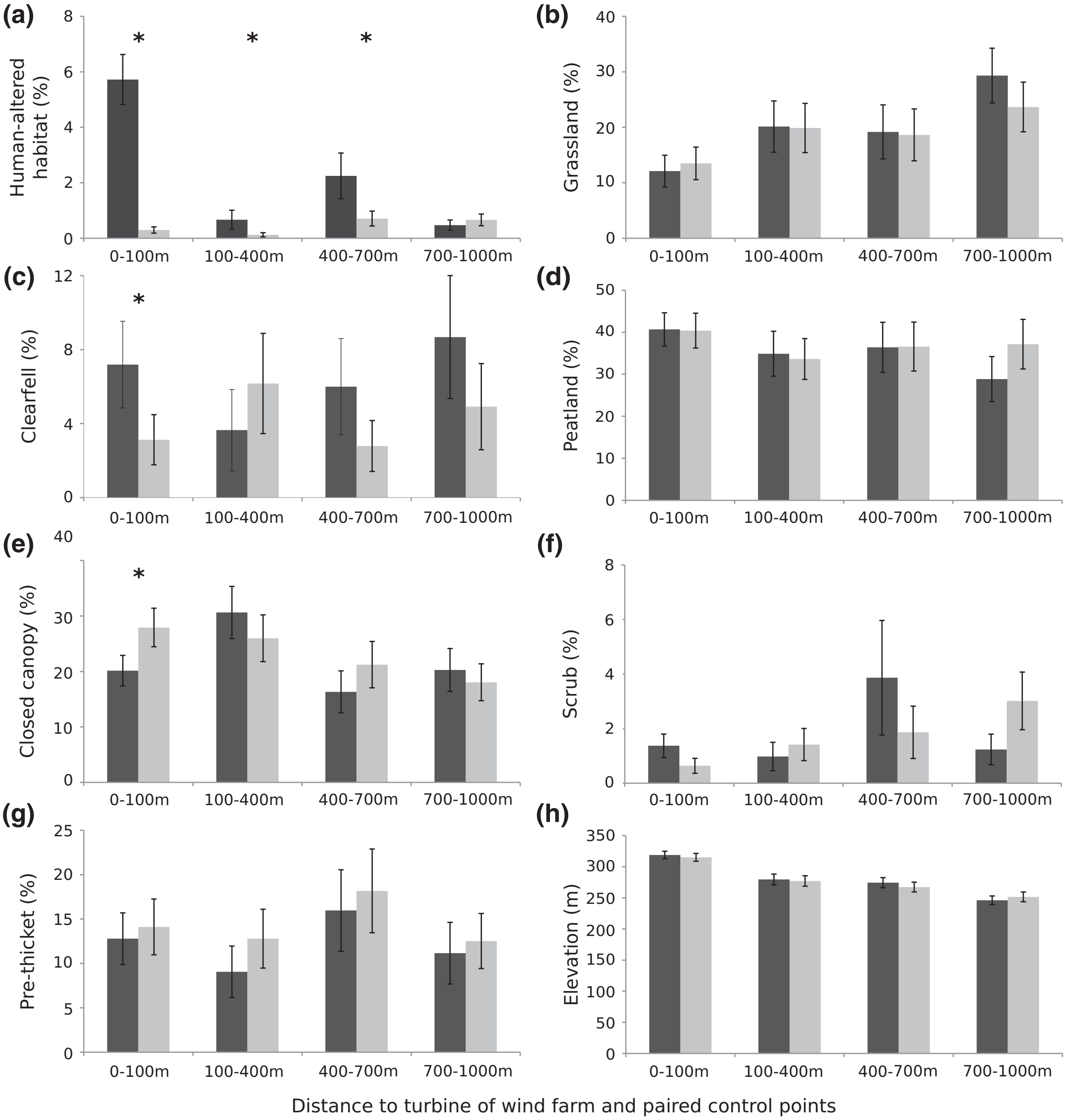

Figure 2. Mean (SE) (a–g) cover of different land-cover types and (h) elevations at wind farms (dark grey) and control sites (light grey) where bird point counts were conducted (, p < 0.05; values on x-axes differ). Control point values are represented at the distance of their corresponding wind-farm point pair.*

at wind farms independent of distance to turbines, although size of the wind farm was negatively related to their densities. These findings indicate a variation in the intensity and scale of the effects of wind-farm development that depends on the ecological association of bird species. Previous research suggests that sensitivity to displacement by wind turbines may be related to species' characteristics, such as their social behavior and habitat use (Stevens et al. 2013; Schuster et al. 2015).

Habitat changes resulting from wind-farm development may help explain the different responses of forest and open-habitat species. Because control survey points were selected to match the habitat and elevation of wind-farm points prior to wind-farm construction (Fig. 2), differences in habitat composition can be attributed to wind-farm construction. Wind-farm points close to turbines had proportionally less closed canopy cover and relatively more clearfell forest and human-altered habitats (bare ground, tracks, and buildings) than did matching control points. Ground clearing and clear felling are often undertaken to make space for wind-farm infrastructure or to maximize wind load (Nayak et al. 2010), whereas access roads increase the area of bare ground. These changes in land use had a net effect of decreasing natural habitat cover at wind farms. In our study, these changes particularly affected closed-canopy habitats, resulted in reductions of habitat for forest bird species, and ultimately led to lower recorded densities. Similar patterns have been observed in response to development of shale gas in forested areas, where changes in land use affect mature forest birds but not birds associated with early successional or disturbed habitats (Farwell et al. 2016). These patterns highlight the importance of planning the precise location of turbines, roads, and other infrastructure in determining which habitats and thus species will be affected by wind-energy development. Presence of wind turbines could also affect bird densities through blade noise, visual disturbance, increased predation risk, or human activity around these structures (Drewitt & Langston 2006; Helldin et al. 2012). Although our findings suggest that changes in land use played an important role, it is possible that these other indirect effects may have contributed to decreased forest bird densities.

Densities of open-habitat birds followed a different pattern from that of forest species. The lack of an apparent gradient in densities at increasing distance from turbines (Fig. 1d) could be explained if either the spatial scale of our study was insufficient (i.e., impact gradients occurred beyond 1000 m from turbines) or if these effects were occurring at a landscape scale. However, typical territory sizes of the open-habitat species are within this scale (Cramp 1988), and for forest species we detected gradient effects within 100 m of turbines. Therefore, it seems unlikely that our study scale was inappropriate, which suggests that for open-habitat birds, effects were operating at a landscape scale. Although there were no differences in extent of open habitat between wind-farm and control survey points (Fig. 2b, d), we did not assess the extent of these habitats in the wider landscape or their quality (e.g., plant species composition, vegetation height). Wind farms are typically located in areas of relatively low value for nature or where access is easy, which may in turn be associated with differences in habitat quality, land use, or habitat management. These, or other differences at a landscape scale that are indirectly linked to presence of wind farms, may play a role in determining bird densities (Lachance et al. 2005). Furthermore, the susceptibility of different species to disturbances (e.g., human activity, movement of turbine blades) may also determine the scale of the effect.

Previous research shows that the extent of wind-farm impacts on bird populations varies considerably across species and regions (Farfán et al. 2009; Pearce-Higgins et al. 2009; Sansom et al. 2016). Where reduced bird abundance at wind farms has been reported, this has generally been confined to areas close to turbines and has not extended into the wider landscape (Leddy et al. 1999; Drewitt & Langston 2006; Pearce-Higgins et al. 2009). Other studies report effects of wind farms specific to certain habitats or to their structure (Hale et al. 2014; Shaffer & Buhl 2016). However, these studies are typically restricted to a small number of species or wind farms, often with limited sample sizes, and efforts to assess impacts on multiple bird species across multiple sites have relied largely on meta-analyses or reviews (Drewitt & Langston 2006; Madders & Whitfield 2006).

Despite the large body of work on best practice for the assessment of effects of wind-energy development on wildlife in general, and birds in particular (Strickland et al. 2007; Astiaso Garcia et al. 2015; Schuster et al. 2015), few studies combine different assessment designs (i.e., before-after, control-impact, impact-gradient approaches) or cover multiple bird species, wind farms, or years (Shaffer & Buhl 2016). Our approach allowed us to compare areas with wind-farm development with control areas of similar environmental characteristics and avoid confounding temporal effects associated with before-after designs (Strickland et al. 2007). By combining this paired control-impact design with an impact-gradient approach, it was possible to evaluate the effects of wind turbine presence and changes in land use while maximizing our ability to detect displacement gradients (NRC 2007). Surveys of breeding birds targeting multiple species allowed detection of nonlethal effects on overall bird densities, as well as of differential effects dependent on species habitat associations.

Ours is one of the first studies to highlight differences in nonlethal effects of wind farms on different bird groups in relation to their ecological association and to demonstrate how the spatial scale of this response may be specific to each group (Pearce-Higgins et al. 2009, 2012). These findings are particularly relevant for planners and policy makers. The differential response of bird guilds reported here suggests that it is possible to locate wind farms and to plan changes in land use in accordance with conservation interests. Depending on regional conservation priorities, it may be possible to locate wind-farm infrastructure such that habitat changes will affect species and habitats of lower conservation concern or even benefit those in need of conservation action. Furthermore, consideration must be given to the ecological role of these habitats and species from a wider ecological perspective. Many of the birds recorded in our study are important prey for key flagship species such as Hen Harrier (*Circus cyaneus*), Merlin (*Falco columbarius*), or Short-eared Owl (*Asio flammeus*), predators that are the focus of considerable conservation effort (Glue 1977; Fernández-Bellon & Lusby 2011; Watson 2013). As such, understanding the effects of wind farms on prey populations and how this may influence these species' foraging habits near wind turbines is essential for their effective management and conservation.

Our study highlights the relevance of assessing the effects of wind farms or other developments on ecological communities or ecosystems as a whole, rather than solely on individual species. Further research into wind-farm impacts on birds should look beyond the effects of turbine presence and take into consideration effects of construction, associated infrastructure, and changes in land use and habitat composition. Similarly, wind-farm planners should consider these potential effects by taking into account not only the precise location of wind turbines, but also that of associated infrastructure (e.g., roads, buildings) and how changes in land use may affect wildlife. Understanding the ways in which land-use changes impact upland ecology is particularly important in the context of continued growth in wind-energy development in combination with other pressures such as afforestation, agricultural intensification, and climate change.

Acknowledgments

We thank all landowners and site managers who facilitated access to study sites for this work and the National Parks & Wildlife Service (NPWS) staff for their contribution to this research. We also thank B. O'Mahony, P. Troake, D. Farrar, D. Watson, T. Nagle, and S. Ingham for assisting with fieldwork and 3 anonymous reviewers for comments on an earlier version of this manuscript. This independent research was funded by several members of the Irish Wind Energy Association, the Department of Agriculture, Food & the Marine, and the National Parks & Wildlife Service.

Supporting Information

Details on site locations (Appendix S1), survey methods and density calculations (Appendix S2), and bird species recorded and their conservation status and densities (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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EXHIBIT
11

Conservation Biology

Contributed Paper

Changes in bird-migration patterns associated with human-induced mortality

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Abstract: *Many bird populations have recently changed their migratory behavior in response to alterations of the environment. We collected data over 16 years on male Great Bustards (*Otis tarda*), a species showing a partial migratory pattern (sedentary and migratory birds coexisting in the same breeding groups). We conducted population counts and radio tracked 180 individuals to examine differences in survival rates between migratory and sedentary individuals and evaluate possible effects of these differences on the migratory pattern of the population. Overall, 65% of individuals migrated and 35% did not. The average distance between breeding and postbreeding areas of migrant individuals was 89.9 km, and the longest average movement of sedentary males was 3.8 km. Breeding group and migration distance had no effect on survival. However, mortality of migrants was 2.4 to 3.5 times higher than mortality of sedentary birds. For marked males, collision with power lines was the main cause of death from unnatural causes (37.6% of all deaths), and migratory birds died in collisions with power lines more frequently than sedentary birds (21.3% vs 6.3%). The percentage of sedentary individuals increased from 17% in 1997 to 45% in 2012. These results were consistent with data collected from radio-tracked individuals: The proportion of migratory individuals decreased from 86% in 1997–1999 to 44% in 2006–2010. The observed decrease in the migratory tendency was not related to climatic changes (temperatures did not change over the study period) or improvements in habitat quality (dry cereal farmland area decreased in the main study area). Our findings suggest that human-induced mortality during migration may be an important factor shaping the migration patterns of species inhabiting humanized landscapes.*

Keywords: differential survival, Great Bustard, long-term monitoring, migration changes, migration costs

Cambios en los Patrones de Migración de Aves Asociados con Mortalidad Inducida por Humanos

Resumen: *El comportamiento migratorio de muchas poblaciones de aves ha cambiado recientemente como consecuencia de las alteraciones ambientales. Durante 16 años estudiamos la conducta migratoria de machos de Avutarda Común Otis tarda, un ave con un patrón de migración parcial (individuos sedentarios y migradores coexisten en los mismos grupos). Realizamos censos de población y seguimos a 180 individuos marcados con emisores de radio para examinar las diferencias en las tasas de supervivencia entre los machos migradores y los sedentarios; y evaluar los posibles efectos de estas diferencias sobre el patrón migratorio de la población. Globalmente, el 65% de los individuos fueron migradores y el 35% sedentarios. La distancia media entre las áreas de reproducción y las post-reproductivas de los migradores fue de 89.9 km y la de los sedentarios de 3.8 km. Ni el grupo reproductor ni la distancia de migración tuvieron efectos sobre la supervivencia. Sin embargo, los individuos migradores tuvieron entre 2.4 y 3.5 veces mayor riesgo de mortalidad que los sedentarios. La colisión con líneas eléctricas fue la principal causa de mortalidad de los machos marcados (37.6% de todas las muertes), y los migradores murieron por colisión con líneas eléctricas con mayor frecuencia que los sedentarios (21.3% versus 6.3%). El porcentaje de individuos sedentarios aumentó desde el 17% en 1997 al 45% en 2012. Estos resultados fueron confirmados por los datos procedentes de individuos marcados: la proporción de migradores disminuyó desde el 86% en 1997–1999 al 44% en 2006–2010. La disminución de la*

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Paper submitted June 23, 2015; revised manuscript accepted May 4, 2016.

DOI: 10.1111/cobi.12758

tendencia migratoria no estuvo relacionada con cambios climáticos (las temperaturas no cambiaron durante el periodo de estudio) o con mejoras de la calidad del hábitat (la superficie de cultivos de cereal disminuyó en el área de estudio principal). Nuestros hallazgos sugieren que la mortalidad durante la migración provocada por las actividades humanas puede ser un factor muy importante en el desarrollo de los patrones de migración de las especies que viven en ambientes humanizados.

Palabras Clave: cambios en la migración, costes de migración, *Otis tarda*, seguimiento a largo plazo, supervivencia diferencial

Introduction

The migratory behavior of many bird species has changed in the last decades. The most frequently observed changes are related to timing of migration and migration distance traveled, both of which are usually explained by climate changes (Newton 2008; Møller et al. 2010). However, little is known about other causes of changes in migration, particularly for species inhabiting human-modified environments. Developed landscapes are characterized by dense networks of railways, motorways, electric power lines, and wind turbines. These infrastructures represent an important risk of mortality for many animals. For example, collisions with aerial cables and electrocution at dangerous pylons are major causes of casualties among birds (Loss et al. 2015). That some of the most spectacular migrations have decreased or disappeared due to human activities has led some to believe that animal migration is an endangered phenomenon that could eventually disappear (Wilcove & Wikelski 2008; Harris et al. 2009).

Mortality is frequently high during migration relative to the breeding and wintering periods; therefore, bird migration may have a large impact on annual survival and population dynamics of migratory species (Newton 2008; Strandberg et al. 2010; Klaassen et al. 2014). Mortality during migration has been associated with natural causes such as bad weather, predation, and poor feeding conditions at stopover sites and with human-induced causes such as habitat destruction or overexploitation, climate change, and human-made obstacles, all of which have been identified as major threats to migrating animals (Newton 2008; Wilcove & Wikelski 2008). Some migrants have lower survival than residents (Adriaensen & Dhondt 1990; Hebblewhite & Merrill 2011), but the question of how events during migration can affect the costs of bird migration is usually not addressed because it is difficult to sample casualties along migration routes (Knudsen et al. 2011).

Given the prevalence of partial migration among many migratory species, several authors highlight that little attention has been paid to how partial migrants respond to environmental changes. These authors recommend the use of long-term data sets to provide new insights (Chapman et al. 2011). Radio tracking large samples of individuals is the best way to determine whether mortality occurred in the nonbreeding areas or during migration, but these data are hard to obtain. Few studies have examined the specific effects of anthropogenic structures on displacement behavior and survival; thus, there is the need to investigate how human activities can affect migration in order to propose how to prevent declines of threatened migrants (Hovick et al. 2014; Klaassen et al. 2014; Sergio et al. 2014).

We investigated how anthropogenic mortality can influence the migratory pattern of a partial migrant. Using Great Bustards (*Otis tarda*) as a model species, we analyzed survival data of a large sample of radio-tracked individuals across multiple migratory annual cycles and long-term surveys of the study population.

The Great Bustard is a globally threatened species that survives in highly fragmented populations, mainly in dry cereal farmland across the Palaearctic, from the Iberian Peninsula to eastern China (Palacín & Alonso 2008; IUCN 2015). The migratory patterns of this species vary: partial and sexually differential in southern Europe (Palacín et al. 2009), facultative in central Europe (Streich et al. 2006), and obligate in the northernmost populations in Russia and Mongolia (Watzke 2007; Kessler et al. 2013). In Spain, Great Bustards are partial migrants; sedentary and migratory birds coexist in the same breeding groups. Migration pattern also differs by sex: many females migrate in autumn to extensive farmlands in the south, whereas males migrate northward in summer to areas where temperatures are lower than at breeding sites (Alonso et al. 2009*b*; Palacín et al. 2009, 2012). Males from the hottest, southernmost regions in Spain have a greater tendency to migrate and migrate longer distances northward. This phenomenon strongly suggests that males migrate to escape summer heat and thus that male partial migration depends on environmental factors (Alonso et al. 2009*b*). Furthermore, previous studies show that males fix their migratory pattern in their first 3 years of life, depending on whether the flock of adult males they integrated in is migratory. In this phase, each immature Great Bustard can change its migratory behavior between years. The decision to migrate is regulated by a complex combination of factors, but social learning plays an important role (Palacín et al. 2011). Although it is commonly accepted that a combination of environmental and genetic factors underlies partial migration (Newton 2008; Chapman et al. 2011; Pulido 2011), recent studies show that in long-lived species social learning is more important than genetic inheritance in modulating several aspects of migration (Hebblewhite & Merrill 2011; Jonker et al. 2013; Mueller et al. 2013). Great Bustards are long lived, and social transmission contributes greatly to the migratory tendency of young and immature individuals (Palacín et al. 2011).

We hypothesized that a human-induced increase in mortality during migration alters the partial migration pattern of a species. Theoretical studies propose that demographic factors can determine a shift between migratory and resident strategies (Taylor & Norris 2007). Moreover, migration mortality and specifically high mortality of migration leaders can lead to the collapse of the migratory fraction of the population (Fagan et al. 2012). However, empirical studies of these predictions are few. Therefore, we analyzed the difference in survival rates between migrant and sedentary individuals, sought to identify the causes of mortality during migration, and examined the effects of mortality on the migratory tendency of this species.

Methods

Study Area

We captured and radio tagged adult male Great Bustards in 29 breeding groups over most of the species' distribution in the Iberian Peninsula (Fig. 1). We defined a breeding group as an aggregation of males and females in a specific area for the purpose of reproduction. As a general rule, both sexes remain faithful to their breeding group throughout their lives. We marked young males and carried out censuses at 20 intensively studied breeding groups in our main study area in central Spain. This held approximately 1600 Great Bustards, of which about 1100 occurred in the special protection area for birds *Estepas Cerealistas de los Ríos Jarama y Henares* (SPA 139) (European Natura 2000 Network; 40°45'N 3° 30'W, 331 km^2, 792 m a.s.l.). In this region, cultivation of dry cereal farmland is extensive and the climate is Mediterranean semiarid.

Capture and Monitoring

We analyzed the survival probabilities of Great Bustards in 107 adult males captured and radio tagged when they were >3 years old and 73 immature males captured and radio tagged as young birds. This sample was composed of individuals >1 year old because it is after 1 year that males decide whether to migrate or not.

We captured adult males during the winters of 1991–2004 with rocket nets and young males in July 1995–2011, when they were 1–3 months old and still dependent on their mothers. Each bird was fitted with a backpack radio transmitter (Biotrack,Warehan, Uk, TW3, powered by 2 for young or 3 for adults AA batteries). The harness was an elastic band. The total weight of transmitter plus harness did not exceed 3% of the bird's weight. Birds were provided with polyvinyl chloride tags to aid visual identification in the field (dorsal tags glued to the transmitters in adult birds and wing tags in juveniles) and location of marked birds after transmitter batteries expired (battery life was up to 6 years in 2-battery units and up to 8 years in 3-battery units). We did not observe plumage damage or behavioral changes in the birds as a result of marking.

We located all radio-tagged individuals through triangulation and subsequent visual observation with telescopes at least once per month but more often several times per month (total 8622 tracking locations). Locations were recorded using a GPS (Garmin 12, Olathe, Kansas) on topographical maps (maximum error 100 m). When a marked bird could not be located from the ground, we searched from the air in an aeroplane (E-24 Bonanza, Beechcraft, Wichita, Kansas) for its signal and later went by car to observe the bird. Aerial tracking allowed us to obtain breeding and postbreeding locations of all marked birds and to avoid the bias derived from emigration outside the study area.

We considered individual migrants when they performed a regular seasonal movement between separate breeding and summering areas (Newton 2008). Migration distance was defined as the maximum distance between separate breeding and summering areas.

We recovered transmitters from dead bustards and estimated their mortality date based on the degree of decomposition of the carcass and our own experience from previous casualties with known death dates. In the few cases, when we found only feathers, bones, or just the transmitter, we considered the date of death the mean between the last time the bird was seen alive and the date when the remains were found. To determine the cause of mortality, we used criteria similar to those described in Martín et al. (2007) and Wolfe et al. (2007) (i.e., the presence of scavenger or predator tracks or other mortality hazards such as power lines or fences in the surrounding area).

Bird Censuses

We carried out censuses of Great Bustards in our main study area in central Spain (Fig. 1). Due to the large size of Great Bustards and to the sparse vegetation in their habitat, reliable censuses (absolute abundance counts) can be conducted that require no correction for detectability (Gregory et al. 2004). Each census was conducted by 2–3 teams. Each team consisted of 2 observers with extensive experience in counting Great Bustards. Teams followed preestablished routes in 4 × 4 vehicles traveling at low speed and stopped frequently to scan for birds with

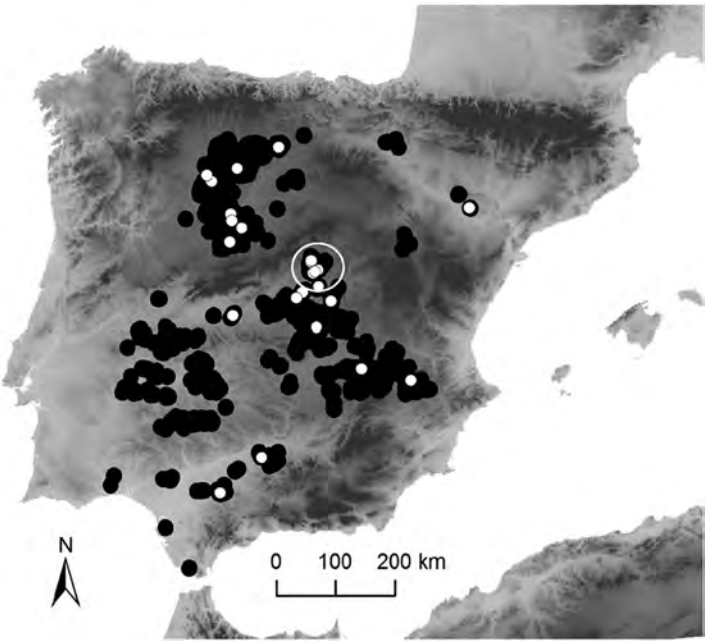

Figure 1. Distribution of Great Bustard breeding groups in Spain (black dots, Alonso et al. 2012); locations of sites where adult males were captured and marked at their breeding areas (white dots); and the location of our main study area (white circle), where population counts and intensive radio tracking were carried out from 1997 to 2012.

binoculars and telescopes (20–60 x). All Great Bustard flocks were mapped on 1:25,000 or 1:50,000 maps. To avoid double counts, teams surveying adjacent areas were in contact via radio. Over 16 years, all censuses were conducted by the same observers using identical methods, which minimized observer biases in the population-trend analyses.

Each year, we carried out at least 2 censuses. The first was in late March (spring), when birds gather at leks, to count breeding individuals. The second was in mid-September to determine their abundance in summer before the first arrivals of migratory individuals occur. In our main study area in central Spain, the first returns of migratory males occur in October, slightly later than the first returns for all of Spain (Fig. 2). Great Bustards show a strong site fidelity to postbreeding areas (94% for males [Palacín et al. 2009]). Thus, annual series of censuses at the same postbreeding areas may adequately represent the tendency of local populations. These counts, together with long-term radio-tracking data obtained from over 600 individuals over 20 years, provided a large data set relative to the dynamics of this metapopulation.

Temperature and Habitat Changes

The average July temperature was used as an indicator of a possible warming trend from 1994 to 2012. We selected July because it is the hottest month of the year in Spain, and summer temperature is the main triggering factor in male summer migration (Alonso et al. 2009*b*). The average temperature for central Spain was obtained from the Spanish Meteorological Agency (AEMET 2013). We measured land-use change during 1990–2000 and 2000–2006 with CORINE Land Cover Changes (EEA 2013) and ArcGis 10 (ESRI 2010).

Statistical Analyses

The Kaplan–Meier method and the log-rank test were used to estimate and compare survival probabilities (Kleinbaum & Klein 2005). The Kaplan–Meier estimator is based on observed data taken on a series of occasions, where animals are marked and released only at occasion 1 and the fate of a marked individual is known with certainty. Fates of individuals were binary coded (1, dead; 0, alive or censored [i.e., lost due to radio failure or other causes]). Binary coding is possible when individuals are radio tagged and the status of all tagged animals is determined at each sampling occasion. Thus, the precision of this method is quite high (Cooch & White 2012). To examine the relationship of migratory pattern, migration distance, and population to survival time, we used a Cox proportional hazard model (Kleinbaum & Klein 2005).

Statistical analyses were performed with SPSS Statistics 19 (IBM Company,Chicago, Illinois, [IBM 2010]). To estimate the annual survival of radio-tagged birds, we used the known-fate model included in MARK (Cooch & White 2012), which is appropriate for data derived from radio-tracking studies in which resighting probability is assumed to be 1. We used the month of marking as a starting date to estimate annual survival (adults were captured in January–February and young birds in July). The logit-link function was used throughout the modeling procedure, and likelihood ratio tests (LRTs) were used to compare different models (Lebreton et al. 1992). Population trends of males in central Spain were calculated using

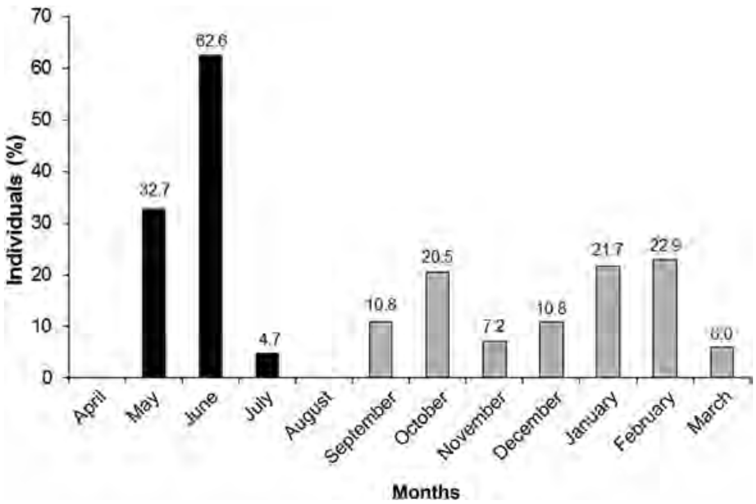

Figure 2. Migration phenology of migrant Great Bustard males (black bars, outward migration, n = *107; gray bars, return migration,* n = *84). Numbers above bars are percentages of migrant individuals.*

TRIM (trends and indices for monitoring data [Pannekoek & van Strien 2001]), which is specifically designed to fit log-linear Poisson regression models to wildlife census data. To test whether breeding and summering population trends differed, we used a model with seasonal effect and a linear effect of time. Nonparametric Spearman's rank correlation tests were used to determine whether the average July temperature in central Spain showed significant trends throughout the study period.

Results

Migratory Pattern and Survival

All breeding groups showed a partial migration pattern. Overall, 117 (65%) of the 180 marked males were migrants and 63 (35%) were sedentary. Migrant males traveled an average of 89.9 km (SD 60.7) between breeding and postbreeding areas (maximum distance 261 km). Sedentary males stayed at the breeding areas all year round and did not perform regular seasonal movements. Their longest movements averaged 3.8 km (SD 3.5). The bulk of outward migration occurred in May and June once mating was over (Fig. 2). The return migration to the breeding areas took place over a longer period, from September to March (Fig. 2).

The survival of adult males did not differ between breeding groups or with migration distance (Table 1). However, mortality of migrants was significantly higher than that of sedentary birds (2.4 higher mortality risk; Cox proportional hazard model, $p < 0.05$) (Table 1). The survival period after being marked was shorter in migrants than in sedentary males (respectively, mean 45.2 months [SD = 4.0], $n = 67$ individuals and mean 63.9 months [SD 3.9], $n = 40$ individuals; log-rank test, $p = 0.001$) (Fig. 3). The estimated annual survival (*S*) was higher in sedentary than in migrant males (respectively, $S = 0.9344$ [SE 0.0182] and $S = 0.8237$ [SE 0.0252]; LRT, $p < 0.001$).

In the sample of males marked as young birds, sedentary males also survived for a longer period than migratory males (respectively, mean 134.7 months [SD 12.0], $n = 23$ individuals and mean 90.6 months [SD 11.9], $n = 50$ individuals; log-rank test, $p = 0.01$). In this sample, migrant males also had higher mortality rates (3.4 higher mortality risk; Cox proportional hazard model, $p = 0.015$), and lower estimated annual survival rates than sedentary males (respectively, $S = 0.5238$ [SE 0.0777] and $S = 0.8663$ [SE 0.07174]; LRT, $p = 0.004$).

Mortality Causes

Collision with power lines was the main identified mortality cause (37.6% of the 77 birds found dead). Other known mortality causes were poaching (9.1%) and collision with fences (2.6%). In all other cases, the cause of mortality could not be identified with certainty. Migratory birds died more frequently by collision with power lines than sedentary birds (respectively, 21.3% of deaths, $n = 117$ males and 6.3% of deaths, $n = 63$ males; Yates corrected chi-square test, $\chi 2 = 5.76$, $p = 0.016$).

Changes in the Proportion of Migratory versus Sedentary Birds

The number of breeding males increased from 1997 to 2012 at the main study area in central Spain at a 5.7% annual rate (Supporting Information). Over this period, the number of males remaining sedentary also increased, but the number increased at a faster rate than the number of breeding males. Thus, the proportion of sedentary males showed a steady increase over the study period, from 17% in 1997 to 45% in 2012 (Fig. 4). The overall mean slope of the increase estimated from 1997 to 2012 was moderate for breeding males (0.0327 [SE 0.006]) and high for sedentary males (0.1032 [SE 0.0139]), and

Table 1. Parameter estimates of the Cox proportional hazard model for migration pattern, distance, and breeding group-dependent survival of adult male great bustards.

Variable	*Coefficient*	*SE*	*Wald*	*P*	*Hazard ratio**	*95% CI*	
Migration pattern	0.903	0.449	4.049	0.044	2.468	1.024	5.948
Distance	0.002	0.003	0.471	0.493	1.002	0.996	1.007
Breeding group	-0.009	0.013	0.467	0.494	1.001	0.996	1.017

**Relative change in mortality risk (increase for values > 1 or decrease for values < 1) of a particular category relative to the corresponding reference category (107 males, 67 migrants, and 40 sedentary individuals).*

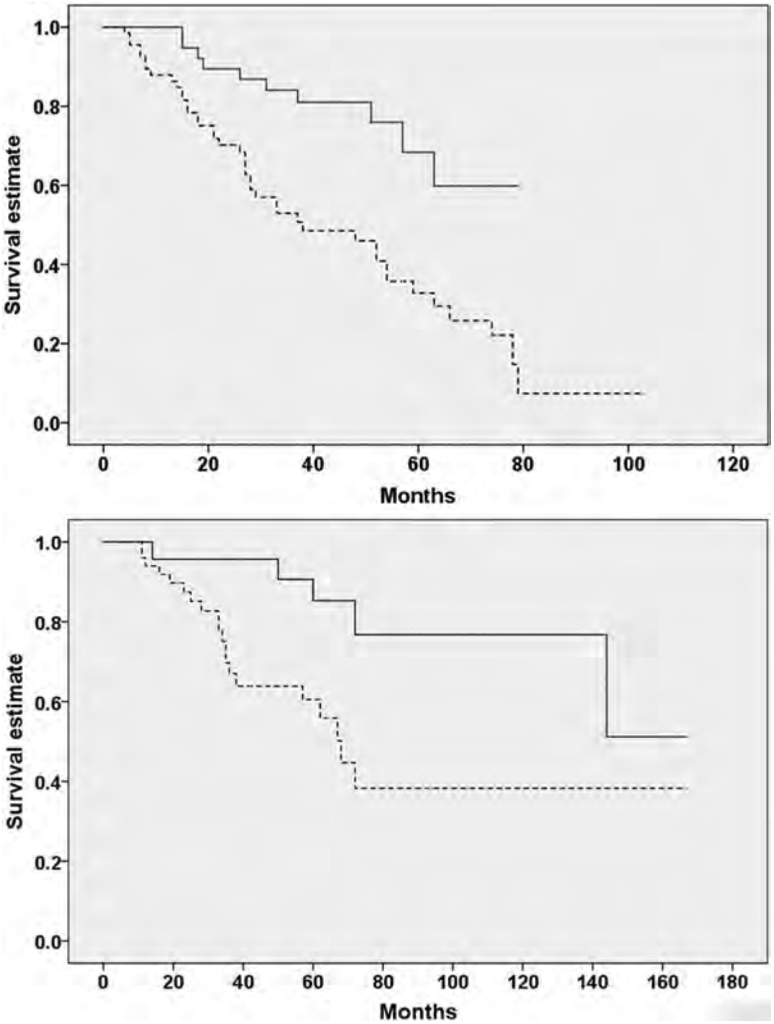

*Figure 3. Kaplan-Meier survival probability estimates of sedentary (solid line) and migrant (dotted line) male Great Bustards: (top) birds marked as adults (*n = *107) and (bottom) birds marked as juveniles (*n = *73).*

both trends differed significantly (Wald test = 24.91, df = 1, $p < 0.000$). Consistent with this trend, from 1997 to 2012, we observed a moderate although significant ($p < 0.05$) declining trend in the number of males at 2 summering areas in central Spain, where some of the migrant males from SPA 139 spent the summer (mean -0.362 [SE 0.0173]) (Supporting Information).

These results were consistent with those for males marked at our main study area. At the beginning of the study (1997–1999), the proportion of migratory males was 86% ($n = 22$ marked males), whereas at the end (2006–2010) that proportion decreased to 44% ($n = 16$ marked males) ($\chi^2 = 5.94$, $p = 0.015$). It is improbable that the numbers of males counted in summer at the main study area were influenced by movements from other areas because no marked bird from other Spanish regions spent the summer in our main study area. Finally, in a sample of 16 males marked in that area from 2006 to 2010, 3 birds shifted from migratory to sedentary when they were 2–3 years old, and they remained sedentary in subsequent years. We never observed a change from sedentary to migratory.

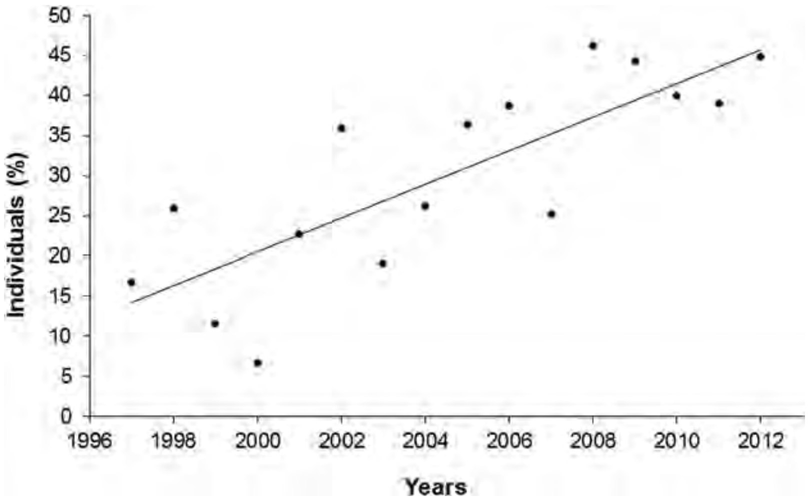

Figure 4. Percentage of sedentary male Great Bustards in the study area in central Spain from 1997 to 2012.

Changes in Temperature and Habitat

The average temperature of the hottest month (July) did not change significantly from 1994 to 2012 at the breeding areas in central Spain (rs = –0.049, $n = 19$, $p = 0.842$) (Supporting Information). The extent of dry cereal farmland in the main study area decreased by 7.2% from 1990 to 2000 and by 2.3% from 2000 to 2006.

Discussion

Migratory Great Bustard males had higher mortality rates than sedentary males. The same result was observed in immature and adult marked birds. Collision with power lines was by far the primary identified mortality cause. More importantly, power lines killed significantly more migrants than sedentary birds. These results show that casualties due to power lines are the most likely cause of decrease in the migratory fraction of the population. Therefore, we conclude that casualties at power lines may be inducing a change in the migration pattern of Great Bustards.

Our study represents a clear case of a human infrastructure causing higher mortality in migrants than in sedentary individuals in a species showing a partial migration pattern. A number of recent studies provide evidence for a rapid change in the migratory pattern of bird populations and both a progressive reduction of the migration distance and an increasing number of the sedentary individuals (Newton 2008; Møller et al. 2010; Pulido & Berthold 2010). A decrease in the migratory tendency in human-altered habitats also occurs with other vertebrates (Waples et al. 2007). Newton (2008) reviewed the recent changes in migratory behavior of birds and found that shifts in sedentary behavior were explained by an increase in the suitability of breeding sites over time. In our case, the increase in the sedentary pattern did not seem to be affected by habitat quality. Rather, habitat quality seemed to decrease over the study period because of the expansion of urbanization and infrastructure (Torres et al. 2011). Because marked birds from other areas of the Iberian Peninsula never spent the summer in our study area in central Spain, an increasing number of males coming from other breeding areas in the last years can also be discarded as a cause of the observed recent increase in the sedentary pattern.

In other long-lived species, social learning is more important than genetic inheritance in modulating several aspects of migration (Hebblewhite & Merrill 2011; Jonker et al. 2013; Mueller et al. 2013). In the Great Bustard, social learning and conspecific attraction could explain the increase of sedentary males as follows. We know that immature males develop their migratory or sedentary pattern during their first 3 years of life, and that their decision to adopt one or the other strategy is associated with their progressive integration into flocks of adult males (Palacín et al. 2011). If recently built power lines kill each year more migrants than sedentary birds, the proportion of sedentary males in each breeding group will grow over the years. Thus, each summer, immature birds deciding whether to migrate will increasingly decide to remain sedentary. All 3 males that changed from migratory to sedentary did it when they were 2 or 3 years old, after they had migrated one or 2 times but when they had not yet completely fixed their migratory strategy. Throughout the immature period, migration of males seems to be facultative, and their decision whether to migrate is an individual decision. After this immature phase, the migratory pattern of each adult male is fixed and does not change over its life (Alonso et al. 2009*b*).

The percentage of migratory males at the beginning of the study was 86%, whereas at the end it was 44%. A balanced payoff of sedentary versus migratory strategies may explain the coexistence of both strategies in a population (Lundberg 1988). At present, the 2 strategies are not balanced in our study population; migrants have higher mortality rates. Each year, there were fewer migrants, and therefore immature birds had more sedentary adults from which to learn a strategy, which led to an increase in the percentage of sedentary males we observed. The progressive loss of migration could have several negative effects. First, more sedentary males in the breeding areas in summer would increase intraspecific competition for resources. Second, in a large-bodied bird like the Great Bustard, individuals remaining sedentary in hot breeding areas incur higher thermoregulatory costs than migratory birds (Alonso et al. 2009*b*). Third, the disappearance of migration in Great Bustards would imply the loss of a mechanism used by some migratory species to expand their breeding range (Newton 2008). Fourth, gene flow could be altered and lead to a reduction of genetic diversity (Clobert et al. 2012). Finally, cessation of migration could eventually lead to the extinction of the population (Fagan et al. 2012).

Climate warming has also been suggested as one of the main factors causing changes in migration patterns (e.g., Møller et al. 2010). In our case, a temperature increase would have caused an increase in the number of migrants because summer migration of Great Bustard males represents an adaptation to escape the summer heat (Alonso et al. 2009*b*). However, there was no clear change in the average summer temperature in our study area. Thus, we discarded temperature as a relevant factor in the shift to sedentary behavior we found.

Power-line casualties may have population-level impacts for other large-bodied species vulnerable to collisions, mainly raptors, cranes, grouse, storks, and waterfowl (Jenkins et al. 2010; Klaassen et al. 2014; Loss et al. 2015). Collision with power lines by Great Bustards may be facilitated by their large body mass (Alonso et al. 2009*a*), which probably limits their flight maneuverability (Janss 2000). Bustards are also particularly prone to collide with power lines because of their reduced frontal visual field (Martin 2011). To solve this problem, considerable funds are currently being invested in central European countries (e.g., European Union LIFE projects [Raab et al. 2012]). This should be considered in Spain, where approximately 70% of the Great Bustard world population lives (Alonso & Palacín 2010) and high-voltage power lines have increased from 1000 km in 1960 to nearly 40,000 km in 2014 (REE 2014; Supporting Information).

Collision with power lines is also a main cause of mortality for other threatened bustards species (Jenkins et al. 2010; Silva et al. 2010; Dutta et al. 2011; Martin 2011). In these species, migration mortality may limit population growth because bustards' demography is sensitive to small changes in adult survival (Combreau et al. 2001; Palacín et al. 2016). Many of their populations are declining, and all 26 bustard species are threatened (IUCN 2015). In addition, power lines may also cause avoidance of some habitat or act as barriers to movement in other grassland and steppe birds (Pruett et al. 2009; Silva et al. 2010). We strongly suggest that plans for new power lines, such as plans for wind-energy facilities, take into consideration the distribution ranges, stopover sites, and migration routes of species vulnerable to collisions, especially in developing countries where power-line infrastructure is expanding quickly.

We found that human-induced mortality may be an important factor modifying the partial migration pattern of Great Bustards and suggest that it may also affect other partially migratory species. The demographic effects of these anthropogenic alterations on many threatened migratory species are still largely unknown and should be further investigated.

Acknowledgments

We thank M. Magaña, B. Martín, C. Ponce, C. Bravo, I. Salgado, A. Torres, P. Sastre, L.M. Bautista, S.J. Lane, E. Martín, and M.B. Morales for their collaboration during field work. We thank the 42 Group of the Spanish Air Forces for their collaboration in aerial location of radio-tagged birds from military aircraft. We thank Comunidad de Madrid, Junta de Castilla y León, Junta de Castilla-La Mancha, Junta de Andalucía, and Gobierno de Aragón for permits to mark the birds. The study was funded by projects PB97-1252, BOS2002-01543, CGL2005-04893/BOS, CGL2008-02567, and CGL2012-36345 of the Dirección General de Investigación. The comments of M. A. Patten and an anonymous reviewer helped us improve this manuscript.

Supporting Information

Results of Great Bustard surveys from 1997 to 2012 in our main study area, trends in mean July temperature in that area from 1994 to 2012, and the amount of high-voltage power lines in Spain from 1960 to 2014 are available online (Appendix S1). The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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EXHIBIT 12

Renewable and Sustainable Energy Reviews 42 (2015) 170–181

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Mitigating wind-turbine induced avian mortality: Sensory, aerodynamic and cognitive constraints and options

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ARTICLE INFO

Article history:
Received 6 May 2013
Received in revised form
13 August 2014
Accepted 1 October 2014

Keywords:
Wind energy
Mitigation measures
Birds
Efficacy
Environmental impacts

ABSTRACT

Because of the fast rate of wind-energy development it will become a challenge to verify impacts on birdlife and construe ways to minimise these. Birds colliding with wind turbines are generally perceived as one of the major conflict issues for wind-energy development. Development of effective and practical measures to reduce bird mortality related to offshore and onshore wind energy is therefore paramount to avoid any delay in consenting processes. The expected efficacy of post-construction mitigation measures for wind-turbine induced avian mortality can be expected to be species-specific with regard to audible, optical and biomechanical constraints and options. Species-specific sensory faculties limit the ability to observe a wind turbine in a given circumstance. Their consequent cognitive perception may depend on the possibilities for associating wind turbines with risk, and discriminating these from other sources. Last but not least, perceived risks may only be evaded when their aerodynamic, locomotive physiology enables them to do so in due time. In order to be able to identify and construe functional mitigation measures these aspects need to be taken into account. Measures eliciting a series of intermittent strong stimuli that are variable in frequency may limit habituation effects; these should only be elicited specifically to mitigate imminent collision. Thus measures either adjusting turbine operation or warning/deterring birds approaching turbines are expected to be most functional. Warning signals may either be based on optical or audible stimuli; however, birds' hearing is inferior to humans while their visual acuity and temporal resolution is higher, but with great differences among species. Implementing effective mitigation measures could reduce the general level of conflicts with birdlife and thus enable both the development at new sites, at sites that have been declared having too high conflict levels, and utilise the wind resources better at specific sites without increasing the conflict levels.

Contents

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http://dx.doi.org/10.1016/j.rser.2014.10.002
1364-0321/

1. Introduction

Reducing emission of greenhouse gases to prevent anthropogenic climate change has boosted the innovation, development and application of renewable energy sources like wind. Unfortunately the ecological and societal footprints may be substantial [1]. Successful development and implementation of wind energy depends on the technological advances and the ability to address environmental challenges. Energy systems for the future must acknowledge simultaneously the challenges of climate change and biodiversity loss.

Focus on unintended bird mortality has become increasingly important recognising that the cumulative effect of mortality from anthropogenic sources may be detrimental to some species. Several reviews have summarised different bird mortality sources and have identified structures posing the highest risk [2–5]. Recent reviews have assessed the extent of annual bird mortality caused by anthropogenic causes to be in the magnitude of 500 million to possibly over 1 billion individuals in the United States alone [6,7]. It is now recognised that for some red-listed species with dwindling populations, human-induced mortality could be fatal [8]. Thus, identifying the causes of mortality and species-specific vulnerability to man-made structures is vital to enable functional design of mitigating measures. Regarding bird mortality due to collision with power lines this was recognised several years ago, in particular the importance of species-specific biomechanical and optical characteristics [9–11]. In a review on bird mortality caused by wind-turbines [12], a main conclusion was that these two aspects should be addressed in particular.

The step from documenting the extent of the mortality caused by anthropogenic factors to successful mitigation is normally a very long one [13]. Mitigating wind-turbine induced bird mortality is particularly complicated due the fact that birds are exposed to collisions with the static structure, as well as being hit by the rotating turbine blades. Thus, it is vital to identify proximate and ultimate factors causing different bird species (or groups) to become wind turbine victims. Targeting these factors is vital to tailor effective mitigating measures for the target species and bird groups [12,14–18]. Still there are reasons to believe that some bird species or groups might be "no-cure species".

Here we review the literature on post-construction mitigating measures to reduce bird mortality due to collisions with wind-turbines and wind-power plants, and evaluate their efficacy from an avian sensory, aerodynamic and cognitive perspective. Mitigation options for other man-made structures were included only where relevant also to mitigation of wind-turbine induced collisions. Pre-construction mitigation measures (e.g. wind-power plant siting) and compensatory measures are not included. We use the term wind turbine for the whole structure that produces energy, including the base (tower), the turbine housing (nacelle) and the rotating rotor blades. A wind-power plant includes several wind turbines and the accompanying infrastructure (e.g. buildings, roads and boat routes, and possible power lines). We also restrict the review to tubular towers, which was early recommended as an important measure for bird survival due to the lack of perches for raptors [19]. Therefore, this review includes (1) minimising impacts by limiting the degree or magnitude of the action (wind-energy production) and its implementation, (2) rectifying the impact by repairing, rehabilitating, or restoring the affected environment, and (3) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action [15]. The main focus is collision mitigation related to birds. Mitigation options for bats and marine mammals were only included where relevant to birds as well.

2. The sensory and aerodynamic ecology of birds

2.1. Bird vision

Vision is the dominant sense of most birds; crucial while flying, finding food, recognising mates or conspecifics, and evading predators. However, behaviour and life-history strategies differ, and birds being e.g. active in periods with poor light at high latitudes, twilight at dawn and dusk as well as nocturnal species, are expected to be vulnerable to crashing into artificial obstacles [20,21]. Activity patterns when the light is poor are a major and complex aspect of bird behaviour, and flight under such conditions does not take place without risks, and "nocturnal behaviour in birds requires an unobstructed habitat" [20].

Regarding vision acuity there is a great variety of adaptations among birds [22,23], a majority being classified as central monofoveal [24], having a single fovea (an area on the retina of very good acuity or resolution due to the high visual cell density) located near the centre of the retina. However, typical predators or hunters (e.g. hawks, bitterns and swallows), have two areas (bifoveal retina) [22,24]. A bifoveal retina and frontal eyes of a falcon allow about 60° binocular or three-dimensional perception but at an expense of a 200° blind zone [22]. An extensive blind zone may help to explain why even some raptors with highly binocular vision e.g. fly into power lines [9,25]. Some birds, like gallinaceous species, are afoveal [24], i.e. they lack or have a poorly developed fovea. This is interesting since tetraonids seem particularly vulnerable to collide with power lines [26]. Birds have a restricted range of flight speeds to adjust information gain when visibility is reduced [27], and e.g. fast-moving object at close distance may escape notice due to "motion smear" (also known as "motion transparency" or "motion blur") [28,29].

Birds are tetra- and pentachromatic (being able to differentiate between two different wavelengths of UV), compared to the human eye, which is trichromatic. This is a common ability of diurnal birds and is due to their special UV-sensitive rods. This ability plays an important role in inter- and intraspecific communication based on plumage UV-reflection, and the ability to, e.g., identify and assess fruit ripeness based on varying UV-reflection of fruit wax layers. As such it is an important factor in understanding bird behaviour [30–34]. Birds probably employ lateral vision for the detection of conspecifics, foraging opportunities and predators, which is normally more important to them than looking ahead during flight in the open airspace [25].

2.2. Hearing in birds

The general anatomy of the bird ear has evolved in a similar way as in mammals, including human [35–38]. However, the auditory pathway is different and more complex, especially in birds most dependent on sounds [39]. Avian ears are located behind and below the eyes, and the openings are protected by feathers. The bird ear, the shape of the head and the location of the two ears enable the bird to determine sound direction and distance [35,40]. This may be of relevance to acoustically alert birds in the vicinity of wind turbines. Directional sensitivity has evolved to a state of great precision in nocturnal hunters as owls listening for small noises made by their prey [38,41], and asymmetry in the outer ear enables some owls to localise sound in the vertical plane [42]. The ears are funnel-shaped to focus sound, and consist of three parts, external, middle and inner ear. The length of the *cochlea* in the inner ear is an index for a bird's sensitivity of sounds [43,44], which is especially long in several wader, pigeon and passerine species, but short in e.g. sea eagle and geese [45,46]. Birds are most sensitive to sounds at 1–5 kHz, with an upper hearing limit at about 10 kHz, but in general have a smaller frequency range and lower sensitivity compared to humans [37,46,47]. Large birds are especially sensitive to low frequency sounds, small birds to high frequency sounds [45]. Hereby, acoustic mitigation measures may be attuned to the specific species at risk. Birds are sensitive to pitch, tone and rhythm changes, and able to recognize other individual birds, even in noisy flocks [35]. As part of their social life, species have specific songs, calls and alerts for different situations; and some species even use sound to echolocate [38,40]. Birds are able to hear details in a sound, and have acute sound recognition skills. Thus they are able to recognize if a call is from predator or conspecific, indicate warning, advertise territory or render information about food [40,48]. This means that also conspecific warning or predator-specific calls may be effective in alerting birds to wind turbines.

2.3. *Other senses*

Olfaction is a chemical sense (chemoreception) and exploits information encoded in molecules moving through air or water [38]. The main characteristics of olfaction are the possibilities to receive information from a stimulus at a greater distance, and the duration of the stimulus may be for a longer time than other sense modalities. The importance of olfaction is direction-dependent. The olfaction in birds has generally lower sensitivity than in human, and has received less research interest than birds' vision and hearing [49]. However, there is evidence that birds may navigate using olfactory cues [50], and have been important in early birds [51]. Information received through olfaction also may become more important as ambient light levels decrease [52]. Olfaction seems to be more important in some bird groups, including several marine bird groups, as fulmars, shearwaters and storm petrels [49]. Several ultimate questions about olfaction are still unanswered, i.e. how birds use their olfactory system. Olfaction is known to play an important role in both foraging and predation risk in some bird species [53,54]. Olfactory cues may thereby both attract or repel birds to/from an area. Magnetoreception, the ability to receive and exploit information about magnetic fields, is documented as important in navigation and orientation in birds [55–58]. This sense makes it possible for the birds to extract information from the Earth's magnetic field, and it has been found in all major groups of birds, both in long-distance migrating and non-migrating groups [56,58]. However, the involved mechanisms at all levels are yet poorly understood, but seem to involve several different mechanisms, even in the same bird [59]. Ruminants have been shown to be disrupted in their body alignment by the extremely low-frequency magnetic fields generated by high-voltage power lines [60]. Thus also man-made electromagnetic fields may affect orientation in magnetic-sensitive species such as birds.

2.4. *Bird flight performance*

Most bird species are able to fly; however, there are major differences among bird taxa with respect to how they master the aerosphere. A species' susceptibility to collisions with e.g. wind turbines may be due to their biomechanical abilities, i.e. their manoeuvrability and agility. Manoeuvrability has been defined as the minimum radius of turn attained by a flying animal and agility as the maximum roll acceleration during the turn initiation, i.e. how fast can the bird change its flight path [61]. Theoretical models for bird flight are reviewed by several authors [27,62–65]. Applying principal component analysis to wing morphology [66] derived statistically independent measures of size and wing proportions. He grouped the major bird taxa within six main categories, determined by differences in aerodynamic performance: “poor” flyers, water birds, diving birds, marine soarers, aerial predators and thermal soarers. Rayner [66] emphasised that species categorised as “poor” flyers probably never had experienced strong evolutionary pressure to enhance their flight efficiency. In a review Bevanger [67] related Rayner's six categories to data derived from the literature on bird species frequently colliding with overhead wires like power lines and found that gallinaceous birds, rails, coots and cranes (“poor flyers”) are among the species most commonly and numerously recorded as victims in America and Europe. “Aerial predators” like several raptor species possess excellent flying abilities (and binocular vision). However, they spend a major part of their life in the air and the probability of crossing power lines (and colliding) is higher compared to ground-dwelling species, which may explain why aerial predators are regularly recorded as collision victims, although in seemingly small numbers [68]. How susceptible “thermal soarers”, i.e. birds with large and broad wings and a decreased wing loading, are to collision is difficult to predict. In short, it seems to be empirical evidence to say that species with high wing loading and low aspect, i.e. the “poor flyers” [66], should be classified in a high risk group as regards collisions with utility structures. The “poor flyers” are characterised by rapid flight and the combination of heavy body and small wings obviously restricting swift reactions to unexpected obstacles. As Rayner [66] emphasised, there are significant variations within some bird groups regarding wing load and aspect ratio, underlining the importance of making accurate analyses among species in the same family to predict the species-specific collision hazard.

3. Cognition and behaviour in birds with respect to disturbance

Species-specific sensory faculties (e.g. vision, hearing), physiological considerations (e.g. body condition, aerodynamics, age, breeding status), behavioural aspects (e.g. motion, response to external stimuli, flight and feeding behaviour), and the surroundings (e.g. food availability, light conditions) limits the birds ability to perceive and respond to wind turbines and wind-power plants. Cognitive perception of wind turbines as risk factors might depend on individual and species-specific possibilities for associating them with risk, and the ability to discriminate from other sources of risk and disturbance [69–71]. Other impulses acting upon the bird simultaneously through its behaviour (e.g. foraging, displaying) may affect detection/perception of wind turbines. In general, continuous exposure to a certain risk may lead to increased discrimination (latent inhibition), but decreased associability (habituation). The spatial cognitive abilities of a species simultaneously enable it to build up a cognitive map of its surroundings where wind turbines may function as landmarks [70,72]. These spatial cues may be processed cognitively either unconsciously (i.e.

the acquisition of knowledge through experience, without awareness of the knowledge thus acquired) or consciously [70]. Thus, the individual's perception may consequently result in either a "passive" or a more stress-related "active" response.

3.1. Perception of disturbance risk

In order to evaluate the possible efficiency of post-construction mitigation measures to reduce bird collisions with wind turbines it might be useful to adopt the hypothesis that nonlethal disturbance stimuli caused by humans are analogous to predation risk [69,71]. However contrary to the framework discussed by Frid and Dill [69] the disturbance stimuli (i.e. wind turbines) are stationary, albeit with moving rotor blades, and the animal is approaching the stimuli instead of being approached. The perceived risk of a wind turbine can only then be evaded when (1) it is being associated with fear by the approaching individual which is generally amplified by increased distance to refuge and prior experience with the risk [69,71], and (2) its locomotive morphology (e.g. wing load, wing aspect) and aerodynamic capability enables the bird to do so in due time [9,63,66]. The efficacy of post-construction measures for mitigating avian collisions with wind turbines therefore depends on the interplay of a species' sensory faculties, behaviour, consequent cognitive perceptions and aerodynamic capabilities for evasion. Many impulses that affect vigilance may act simultaneously upon the bird through its behaviour (e.g. foraging, courtship or territorial defence), and limit the detection and/or perception of wind turbines as potential dangers [73]. Social learning about predators (i.e. a wind turbine), and increased vigilance, may be faster and more robust in species in which alarm behaviour reliably predicts high risk [74]. Blumstein [75] reviewed flight initiation distance (FID), as a metric of awareness, in 150 species of birds. His findings strongly suggest that an important first step in implementing mitigation measures based on FIDs should be to evaluate the potential, site-specific, species at risk, and their life-history strategies. FID is measured in relation to an approaching moving object (a human walking towards the bird in focus) so it might not be directly related to bird's behaviour against a stationary object such as a wind turbine. However, it might be regarded as important in order to be able to judge the prospects of mitigation measures where information on species-specific FIDs can be used to develop mechanisms that might prevent birds from colliding with wind turbines by increasing their FIDs. In that aspect one should, however, strongly consider the possibilities that distracting elements (sounds, flashing lights etc.) could reduce FIDs rather than increase them [76] or increase vulnerability to predation [77]. In order to use bird vigilance as a tool for developing mitigation measures two factors should be considered: (1) the stimuli presented should, as far as possible, resemble a predation situation or a situation that the target species recognises as a potential danger that should be avoided, and (2) it should be presented in a way that minimises the risk of habituation – i.e. it has to be strongly correlated with the probability of colliding with the wind turbine if the stimuli is absent.

3.2. Habituation and learning

Continuous exposure to either the actual wind turbine or a proposed post-construction measure for mitigating avian collisions with wind turbines are subject to learning in birds, and may lead to decreased associability with disturbance, and also increased habituation. If it is possible to introduce a mitigation measure increasing the birds' awareness of the dangerous turbine blade or tower, and maintain this awareness over time, this measure will be more effective. Depending on the measure proposed, its efficacy may deteriorate over time when birds habituate to them or learn by association their harmlessness [78–81]. Stimuli that are only elicited with increased collision risk, enables birds to habituate to this specific stimulus while leaving it responsive to other stimuli (i.e. stimulus specificity) [78]. In relation to post-construction measure for mitigating avian collisions with wind turbines, their efficacy over time may be maintained by taking into account aspects enhancing dis-habituation such as eliciting multiple stimuli and repetitions of these. According to behavioural characteristics of habituation [78], mitigation measures should elicit a series of intermittent strong stimuli that are variable in frequency. The stimulus should, however, not become too repetitive, and specifically be elicited to mitigate collision only. There seem to be no mitigation study at wind turbines examining factors and stimuli leading to learning by association, habituation or other learning mechanisms in birds [81,82], although several proposals have mentioned the problem, especially when using auditory measures. In this review we use the term habituation, the simplest form of learning [79,81,82], to represent and including all mechanisms of learning, because there have been no mitigation study revealing the relative importance of habituation (waning of responsiveness), associative (classical and operational conditioning) or social learning mechanisms. Birds may learn by association [81–83], both to perceive the danger of the turbines and the harmlessness of a specific mitigation stimulus. Birds also use social learning e.g. in recognition of predators and disturbances [81,84], and this may be used by birds also near wind turbines, i.e. when birds perceive a collision by other individuals, and may be important also at several mitigation measures.

4. Assessment of measures mitigating avian collisions with wind turbines

4.1. Methodology

The overview of possible post-construction mitigation measures is based on existing reviews on the topic [12,15,18,19,85–89], keyword searches in ISI Web of Science, Google Scholar and Internet sites (see Table 1 for keywords used), and by contacting experts internationally (researchers, and representatives from industry and government agencies) directly. This broad approach was deemed appropriate to retrieve as much information as possible both from scientific (peer-reviewed journals, books) and grey literature (reports, articles, commercial patents/products, brochures, web sites). In total 77 references to 26 possible mitigation measures to reduce bird collisions with wind turbines were collected (Supplementary appendix). Possible mitigation options to reduce collisions between birds and wind turbines in existing wind-power plants can be categorised as either turbine-based or bird-based. Mitigation options on turbines encompass

Table 1
Keywords used literature databases (ISI Web of Knowledge) and on Internet search browsers (Google, Google Scholar).

General searches were combined with "wind turbine*" AND bird*:
mitigation/mitigate/mitigating/mitigate*
mitigation experiment*
temporary shutdown
bird collision*
bird mortality
avian collision*
avian mortality
deterrent/deterrence*
Including different combinations of these keywords

wind-power plant design, micro-siting of turbines, repowering and operation. Such measures have small or only indirect effects on bird behaviour, but may have high effects on bird mortality. The other approach is to directly affect bird behaviour. The mitigation options affecting bird behaviour encompass turbine design, deterrence/harassment and habitat alterations. The latter may be either inside (decreasing the attractiveness of the area), or outside the wind-power plant area (increasing the attractiveness of other areas).

To evaluate the efficacy of the proposed measures to mitigate wind-turbine induced bird mortality we employed a set of six qualitative criteria; partially divided into (1) turbine-specific or (2) bird-specific aspects. Criteria I–III focus on the expected efficacy of the stressor-exposure-response gradient used in ecological risk assessments [90]. Criteria IV and V assess the potential for ensuring effectiveness over time [78]. Criterion VI assesses the costs involved from an operational, economic and societal perspective. The six criteria are defined as follows:

Criterion I – Stressor: The proposed measure elicits a weak/medium/strong stimulus with regard to the (1) turbine-specific event (e.g. operational, design), or (2) bird-specific intensity (e.g. luminance, decibel) and/or spectral/auditory sensitivity (e.g. visibility, wavelength range).
Criterion II – Exposure: The stressor of the proposed measure results in low/medium/high detection with regard to (1) turbine-specific event regime (e.g. schedule, trigger distance), or (2) bird-specific perceptual range and exposure regime (e.g. exposure time, repetition).
Criterion III – Response: The exposure to the stressor of the proposed measure elicits a weak/medium/strong (1) turbine-specific risk reduction, or (2) bird-specific evasive response.
Criterion IV – Habituation: The proposed mitigation measure results in high/medium/low levels of habituation or other forms of learning in birds, reducing its efficacy.
Criterion V – Specificity: The proposed mitigation measure has a low/medium/high specificity to mitigate collision only, and/or repetitive levels.
Criterion VI – Implementation: The proposed mitigation measure comes at a high/medium/low cost for installation, maintenance and/or energy production; or may result in societal conflict (e.g. annoying lights or noise).

The assessment builds on the expected or – when available – observed, estimated or tested efficacy of the proposed mitigation measure. For each mitigation measure the six criteria were scored from one to three with three as most preferable (Table 2).

4.2. Turbine-specific mitigation options

Measures to mitigate collision risk through adjustments in turbine design and/or operation do not directly affect the sensory faculties, but rather aim at reducing the risk by reducing the birds' exposure to the hazard (i.e. the potential for collision irrespective of events; risk = hazard × exposure). The stressor (Criterion I) may here be interpreted as a form for incentive, rather than a negative stimulus.

Table 2
Evaluation of the efficacy of measures to mitigate turbine-induced mortality in birds.

Mitigation measures		**Criterion I: stressor**	**Criterion II: exposure**	**Criterion III: response**	**Criterion IV: habituation**	**Criterion V: specificity**	**Criterion VI: implementation**	**Total score**
Turbine-specific								
Wind-power plant design		1	2	2	1	1	1	1.33
Repowering/larger turbines		1	3	2	2	1	2	1.83
Removing selected turbines		2	2	2	2	3	1	2.00
Relocating selected turbines		2	1	2	2	2	1	1.67
Altering turbine speed		3	3	3	2	3	3	**2.83**
Temporary shutdown		3	3	3	2	3	2	**2.67**
Bird-specific								
Visual cues								
Marking/painting	☼	2	3	1	1	1	2	1.67
Visibility: reducing motion smear	☼	1	2	2	2	2	3	2.00
UV-coating	☼	2	2	2	2	2	3	2.17
Reflectors	☼	2	3	3	2	2	3	**2.50**
Minimal turbine lighting	☽	1	1	1	3	1	3	1.67
Turbine lighting regime	☽	2	2	2	3	2	3	2.33
Visual deterrence	☽	3	3	3	3	3	1	**2.67**
Laser	☽	3	3	2	3	3	2	**2.67**
Acoustic cues								
Acoustic harassment		3	1	2	1	2	2	1.83
Audible deterrence		2	3	3	3	3	2	**2.67**
Other sensory cues								
Electromagnetism		1	1	1	3	1	2	1.50
Olfaction		3	3	2	2	1	2	2.17
Habitat alterations								
On-site								
Habitat quality		2	1	2	2	1	2	1.67
Food availability		1	1	1	2	1	3	1.50
Off-site								
Habitat quality		2	3	2	2	1	2	2.00
Food availability		2	3	2	2	2	3	2.33
Breeding habitat		2	2	2	2	2	2	2.00
Roosting places		2	2	2	3	2	3	2.33
Other measures								
Funding wildlife research		NA	NA	NA	NA	NA	NA	NA
Monitoring fatalities		NA	NA	NA	NA	NA	NA	NA

Recently, movement models have shown to be able to provide insight into and identify possible impacts of offshore wind power plants at the planning state [91]. Changing the design of a wind-power plant by placing turbines in tight clusters was assessed to have limited efficacy. Although the total impact area is reduced by clustering turbines; at the same time the entire area will become inaccessibly to the birds due to reduced openness. Tighter placed turbines may be perceived as a single landmark (versus several turbines within natural habitat) to be avoided. However, it remains as yet unclear to which extent this results in possible adjustments in their spatial cognitive map [72] and how this affects a species' behaviour and spatial ecology [73]. Also, implementation costs in a post-construction situation are high; both with regard to relocating turbines and due to reduced wind capture. In general, fewer and larger turbines are thought to be preferred over many small turbines with regard to minimising collision risk to birds. Primarily in wind-power plants in the USA, older turbines with lattice towers and/or smaller turbines were replaced by larger tubular towered turbines. Repowering may result in dramatic changes with regard to exposure; and has been observed to lead to clearly reduced mortality in the Altamont Pass Wind Resource Area [18,92–95]. Other studies have however shown little [96,97] or even opposite effects [98] on fatality rates. However, birds may habituate to these larger structures, especially because repowering does not involve any specificity towards collision-reduction. Also, any benefit may only occur in old-generation wind-power plant facilities, such as was the case in the Altamont Pass Wind Resource Area. The implementation costs are lower relative to changing wind-power plant design because repowered turbines are likely more efficient in generating energy.

Micro-siting options (i.e. removing or relocating turbines) aim at identifying locations with increased risk for collisions. In wind-power plants where turbines were placed at more hazardous locations to bird collisions, these were either removed or relocated. Micro-siting has been proposed in agricultural areas [99], wetlands [100] and along ridges with many soaring raptors [14,18,93,94,101]. Removing "problem" turbines will specifically reduce mortality at that location, but may possibly lead to a shift of the problem to other turbines. Relocation of "problem" turbines instead may create increased collision risk elsewhere; and has therefore a lower expected efficacy. It has for example been suggested that outer turbines and turbines at the end of each row may experience higher risk of collision [14,102]. If this is the case, removing outer turbines will not remedy, only shift, the problem. Unless "problem" turbines were placed at specific hazardous locations, such as breeding sites [103], migration bottlenecks [12,104] or topography creating thermals [104,105], the collision risk may be expected to be reduced when such turbines are removed or relocated. The efficacy of micro-siting options is likely very site-specific and should preferably be done prior to the construction of the wind-power plant.

Most proposed mitigation measures focus on adjusted operation; either through altering turbine speed (cut-in speed, feathering) or temporary shutdown of turbines. These measures may only mitigate mortality due to collisions with rotor blades, and not for birds colliding with the turbine structure. Several studies have shown the highest activity of bats or birds at low wind speed [104,106–111]. To minimise collisions at low wind speeds, when energy output may be marginal, the cut-in wind speed at which the turbines start to produce energy was increased. For bats this usually happened around 6 m/s [106–109,111], for raptors collision risk declined at wind speed over 8 m/s [104]. Whether changing the cut-in speed at lower wind speeds, possibly at specific turbines, may be an effective way of reducing mortality depends on the species' flight behaviour. For birds that are mainly active at lower wind speeds, such as large soaring birds (e.g. raptors, herons and storks) that use thermal updrafts [112–114], the measure may specifically reduce the risk in such situations. Such a reduction of the risk window may come at relatively low costs because energy generation at low wind speed is limited (annual power loss $\leq 1\%$ of total annual output) [106,108]. Temporary shutdown has been tested in periods with high bird activity, or when birds moved too close to the turbines [93,115–119]. Methods used to assess when birds flew too close to turbines were either through visual observations [116,118] or avian radar [119,120]. An effective use of this measure, however, depends on a good monitoring scheme to limit unnecessary shutdown and thereby loss of energy generation. Especially when shutdown is restricted to specific events of near-collisions, the efficacy will likely improve as this will limit possible habituation effects. Too large shutdown periods may cause birds to adjust to this new situation, leading to reduced avoidance of the turbines [121,122]. However, other studies indicated that birds may primarily be affected by the actual turbine structures [123].

4.3. *Bird-specific mitigation options*

Another option for mitigation of collisions is to alert birds to the turbines or affecting bird behaviour. Alerting birds to the turbine structure may encompass making the rotor blades more visible, where reduction of motion smear [29] has been the major incentive. Alternatively mitigation measures have been proposed to dissuade birds from coming too close to the turbines through sensory cues. The efficacy of such measures is dependent on the birds' perception and response to the sensory cues (i.e. stressors). It is therefore crucial to take into account the sensory constraints placed upon the species of focus [124]. Mitigation options include passive and active visual cues (e.g. painting or lighting), audible deterrence/harassment, and to a lesser extent other sensory cues (e.g. olfaction, microwaves). In addition, habitat alterations either within or outside of the wind-power plant area may affect the birds' behaviour. Although great differences exist among species, generally birds' hearing is inferior to humans while their visual acuity and temporal resolution is higher [29,37]. Consequently, most measures are based on visual cues.

Mitigation measures based on passive visual cues include use of marking, reducing motion smear, reflectors or UV-coating. Marking patterns that have been proposed include scarecrows, conspecific/raptor models or displaying conspecific corpses. Stimuli placed on the ground have been suggested be most visible to birds due to the higher resolution of their lateral fields of view [25]. However, due to the lack of movement habituation may be more pronounced [125]. Because of this, and the lack of specificity towards reduction of collisions the efficacy of marking patterns is deemed limited. As a result of the work by Hodos [29], reduction of motion smear have been proposed as a measure to increase the conspicuity of the rotor blades enabling birds to take evasive action in due time. The ex-situ experiments by Hodos [29] indicated that painting one of three blades black reduced motion smear most. This measure has not been tested in-situ and merits further investigation [88,126]. Depending on whether decreased visibility of rotor blade tips is the cause of collisions, reducing motion smear may enhance the exposure potential. Especially when the motion smear pattern appears to be "moving" this may benefit its efficacy, and reduce habituation, as the frontal vision in birds may be more tuned for the detection of movement [25]. However, this measure does not directly reduce collision risk, but rather alerts birds to the presence of the rotor blades. As for all measures based on passive visual cues, UV-coating only works during daytime. UV-coating on rotor blades to increase their visibility has been proposed and tested in the USA with unclear conclusions on its efficacy [127,128]. This measure is expected to have similar effects as for reducing motion smear, although we scored it higher on the stressor criterion because the UV-coating lies within a, for birds, sensitive spectral wavelength [129]. Reflectors in the form of mirrors and aluminium/silvered objects – one could even think of holograms – may also provide to be an effective way of scaring birds [125]. However, reflectors will only be effective when they reflect (sun)light and lose their efficacy between sunset and sunrise, they were recommended in combination with other methods of scaring [125]. At daytime, when also most birds are active, they may create an ever-moving myriad of lights reflecting off the blades. Due to these changing reflections, the blades may become more visible and may attract attention to them resulting in increased responsiveness in the birds. However, as this measure is not specifically minimising collisions, but rather aims at increasing the conspicuity of the blades and alerting birds to their presence, habituation may occur. Implementation costs should be relatively low, although reflectors on the blades may require regular cleaning.

Mitigation measures based on active visual cues include minimal use of turbine lighting, adjustment of turbine lighting regimes, visual deterrence or laser. Minimal use of turbine lighting has been proposed especially for bats and nocturnal migrating birds. However, observations showed no differences in fatality rates between lit and unlit turbines [130–132]. Even though nocturnal (migrating) birds may be attracted to the (red) flashing or steady-burning safety lights [87,133]. Although the implementation costs – air traffic safety implications aside – should be limited, minimal use of lighting may have limited impact for reducing collisions. Although nocturnal birds may be prevented being attracted to the turbine lights, they are also not alerted their presence.

Adjustment of turbine lighting regime on the other hand has given more promising results. Using pulsating lights instead of steady-burning lights reduced bird fatalities at guyed communication towers significantly [134]. White strobe lights have also been proposed instead of the standard red lights [88,126]. However, experiments have shown that nocturnal migrating birds were least attracted and disoriented by blue and green lights especially on overcast nights [135]. Adjustment of turbine lighting regime therefore scores higher on the stressor-exposure-response scale, compared to minimal use of turbine lighting. Although this still has to be implemented and tested in-situ, this measure aims at alerting birds to the turbines while minimising detrimental attraction and disorientation.

Visual deterrence includes the use of strobing, flashing, revolving lights causing a temporary blinding and thereby confusion effect [136]. This measure will be most effective at low light levels, and may therefore mainly help mitigate collisions of nocturnal birds. Habituation may be reduced through randomized selection of at least two strobe frequencies; however use of bright lights may cause visual nuisance for local residents [125]. Also, its efficacy will be enhanced greatly when the visual deterrents are emitted only in situations when birds are in close vicinity of a turbine. This requires a functional, e.g. based on video [137] or avian radar [119,120], system to continuously monitor bird flight behaviour. Depending on the exact wavelength, luminance and exposure regime used this will likely result in high levels of evasive responses. For example, aircraft mounted with lights led to quicker evasive responses in Canada geese *Branta canadensis*, and was suggested to be most effective – given their spectral sensitivity – when the lights peak in the ultraviolet/violet range (380–400 nm) [138]. However, the implementation may be more challenging as such deterrence systems should be installed on all ("problem") turbines and require trustworthy triggering of the deterring stimulus (i.e. both with regard to Type I and Type II errors). Using laser renders similar efficacy as for visual deterrence. The difference being that laser may be directed more accurately at an approaching bird [125,136]. However this accuracy may also be its limitation as it assumes that it will be possible to pinpoint a flying bird. The visual nuisance of laser may however be less pronounced than for lights. Lasers also work best under low light levels. Something that has not been proposed is to utilise UV lasers that sweep upwards during night time encircling the rotor swept zone. UV lasers are invisible to the human eye but may deter nocturnal birds from entering the rotor swept zone.

Acoustic-based mitigation measures can either be in the form of audible harassment or deterrence. Audible harassment has been implemented especially at airports, agriculture and aquaculture [139–142]. It involves emitting hard sounds to scare away birds from an area. Methods used include: gas cannons, shooting, pyrotechnics, and ultrasound [125,143]. Most of these sounds will have to be emitted at high intensity and will therefore create audible nuisance for local residents. Ultrasound should largely be inaudible to humans, but has shown varying results in deterring birds [142,143]. Also, auditory harassment is subject to habituation and may therefore only have short-term benefit [19,37,125,136,142]. Effectiveness may be enhanced by varying firing frequency and direction, and/or using a combination of methods [136,142]. Dooling [37] suggested, based on his review on birds' hearing and options for mitigation, that an acoustic "whistling" cue in the region of best hearing for birds (2–4 kHz) help birds hear the blades while adding almost nothing to overall noise level. Instead of using artificial sounds, also bio-acoustic sounds may be used, such as bird alarm and distress calls [125,144]. Because of their biological meaning, these are thought to be more resistant to habituation. Although the response to bio-acoustic sounds likely is very species-specific, it may also evoke responses in other species [145]. Whereas acoustic harassment aims at scaring birds irrespective of where they are, audible deterrence warns/dissuades birds when approaching a turbine. Similar to visual deterrence, this requires functional monitoring systems to record hazardous bird flights [137]. What remains as yet unclear is at what wavelength and decibels sound should be emitted to evoke the most urgent response and be most effective [146,147]. Also the exposure regime (i.e. schedule, trigger distance) when replaying e.g. distress calls to deter birds, and variety in these parameters, affect its efficacy [136]. This may limit habituation effects, especially when in multiple-stressor set-up.

Other sensory cues that have been proposed as deterrence measures are electromagnetism and olfaction. Magnets and especially microwaves can create magnetic fields that are thought to disorient birds. Although this seemed effective for bats [148,149], it is expected to be of limited effect to deter birds from an area [140,150]. A behavioural evasive response may only occur when electromagnetic radiation is so intense to pose a potential health hazard to the birds but also humans [140]. Olfaction is known to play an important role in both foraging and predation risk in some bird species [53,54]. At airports, distributing toxicants in sub-lethal doses may cause disorientation and erratic behaviour and birds [125]. Applying behavioural repellents, however, has little specificity to reduce collision risk, its spatio-temporal permanence may depend on terrain and weather conditions (e.g. wind direction and speed, precipitation) and habituation may occur. Also, when too high doses are applied this may present a hazard to (non-targeted) birds [140].

4.4. Habitat alterations for mitigation

Finally, birds may be discouraged either by making areas near the turbines less attractive, or to enhance the habitat quality outside the wind-power plant. On-site habitat alterations (i.e. inside the wind-power plant area) which have been proposed include clear-cutting forests [131,151] or making open vegetation near turbines less attractive for either birds or their prey [87,99]. The efficacy of on-site habitat alterations likely depends on the importance of the habitat for the given species. When a wind-power plant is located in prime habitat for a species, this area may function as an ecological trap [152]. Still, unless the preferred habitat is altered dramatically (i.e. non-habitat), the area may still be frequented. Also, habitat alterations will result in habitat loss, or gain, for other non-targeted species (previously) not affected by the turbines. The loss of e.g. foraging or breeding habitat may lead to shifts in range use; however it does not preclude moving through the wind-power plant. The specificity is therefore limited, and the extent of habituation may depend on e.g. population density, territoriality and the availability of quality habitat in the surrounding landscape. Alternatively, the prey availability may be reduced inside the wind-power plant. This has mainly been proposed for e.g. eagles [153,154], vultures [155,156] and owls [115]. Obligatory scavengers aside, removal of carcasses or live prey (e.g. through rodent control) may have limited efficacy to reduce collisions within a wind-power plant. Only in specific situations when birds of prey or scavengers are attracted to the turbine bases to forage for prey using the rocky foundations as (burrowing) habitat or for collision fatalities [14,18,94] may localised rodent control or removal of fatalities show any effect. Better, however would be to alter the rocky substrate at the tower base to less attractive habitat for prey.

Off-site habitat alteration measures aim to increase the attractiveness of other areas outside the wind-power plant. These include the creation of novel habitats, breeding sites, food availability, and roosting sites or perches for birds. Although attraction of birds to improved or novel habitats outside the wind-power plant may present the birds with a stronger stimulus to shift their habitat preferences spatially, this has so far not been documented [99,157,158]. Simultaneously altering habitat quality both on- and off-site may, considering habitat alteration options alone, maximise its efficacy. However, the lack of specificity of this measure with regard to the species which are targeted may make this of less interest from a conservation point of view. Some success has been observed when presenting birds of prey with alternative feeding opportunities outside a wind-power plant [155,159]. However, this assumes the possibility for off-site prey base improvements relative to the on-site foraging quality [160]. Specifically protecting existing or creating artificial breeding sites has been proposed for raptors [19,153]. Another option is to erect perching towers outside a wind-power plant, which was suggested to have potential for offshore birds [88,126]. Although this may indirectly enhance breeding success or survival in a local population affected by increased turbine-induced mortality, it does not preclude these birds moving through and utilising the wind-power plant to forage. Any reduced exposure therefore influences only part of their ecology. Removal of existing breeding sites in the vicinity of a wind-power plant has so far not been proposed as a possible mitigation option due to the fact that this will lead to an additional impact on an already vulnerable population. Increased perching opportunities previously not available to the birds (e.g. offshore) may also attract them to the turbines, reducing its efficacy. Much of the same conditions as for habitat alterations will apply also for breeding sites and roosts/perches; the location of the turbines with regard to available quality habitat in the surrounding landscape greatly affects its expected efficacy.

4.5. Other measures for mitigation

Finally, some mitigation options have been proposed which may benefit the species indirectly. When mitigation may not be possible or did not have its desired effect on the species at risk, funding research may render new insights into the species' ecology for long-term conservation [87]. In many cases, the knowledge base on which mitigation measures are proposed is insufficient. An improved understanding on why, when and where a species may be expected to be most at risk can be assessed by studying e.g. flight behaviour, habitat and food preferences and causes of mortality. This may offer novel options for offsets at biological appropriate locations. Employing appropriate fatality monitoring programmes [17,161] does not directly reduce collisions, but may render increased insight into where and when which species are most at risk. This may then in the future direct possible operational – or other – mitigation measures. However, such a monitoring scheme only sets focus on possible spatial and temporal correlates in fatality patterns; it does not include other biologically relevant aspects such as habitat preferences and flight behaviour.

5. Concluding remarks

Minimisation of impacts from wind-energy development should always be addressed in the consenting process through the “avoid – minimise – compensate” mitigation hierarchy [162]. Collision-reducing mitigation measures should therefore always be preceded by a thorough siting process. As becomes clear in this review, post-construction mitigation measures should be species-specific and directed towards the most collision-prone species. However fatalities may also be highly seasonal and site-specific. For instance, white-tailed eagle [163] and griffon vulture (*Gyps fulvus*) [116] mortalities have been demonstrated to be highly seasonal, and related to habitat structure; most fatalities were clustered to a limited number of turbines. This fact was used when implementing a programme where the wind turbines were stopped when griffon vultures were observed near them, reducing vulture mortality rates by 50% while the energy production was only reduced by 0.07% per year [116]. The choice of mitigation measures should therefore be tailored for the species-at-risk at each wind-power plant separately. For instance, at the Smøla wind-power plant in Norway impacts on white-tailed eagles are perceived to be significant [163–165]. Studies, however, indicate that this day-active species neither actively avoids nor is displaced by the turbines [103,166,167]. Collision risk reduction was therefore proposed to be done either through audible deterrence or enhancing the visibility of the rotor blades.

On-site mitigation measures proven to have been effective may also have an indirect effect on the overall habitat quality. As a result of visual or acoustic deterrence measures, birds may choose to move away from the wind-power plant area to other possibly suboptimal habitat. The effect of such measures on the entire population may therefore be larger than the effect of some birds colliding with wind turbines. Although there is a general preference for on-site mitigation over off-site mitigation, sometimes off-site mitigation may result in greater net benefits to affected species and their habitats [86]. Possibly development of wind energy and transmission line construction on disturbed lands may offer the potential to dramatically reduce associated wildlife impacts [1]. In addition, preclusion of construction activity near breeding territories and/or during the breeding season may be preferred [168].

Because sound intensity is reduced with square number of the distance, possibilities to use audible deterrence as mitigation measure will be best at small distances. Given the social importance of sound in birds, utilising sounds with a biological meaning (e.g. predator sounds or warning calls) may be useful in mitigation measures [46]. In general acoustic devices are effective only for a short time [37,47], and the most effective use of acoustic signals is when they are reinforced with activities that produce death or a painful experience to some members in a population [46]. Sound-level changes of only a few decibels and stimuli duration may e.g. be important to improve the use of acoustic devices to birds' responses [146]. Utilisation of multiple stressors may be more effective to minimise collision risk. For instance, with respect to visual cues combining passive measures (e.g. coating) with active measures (e.g. lighting) reduce collision risk both at high and low light levels, respectively. We would like to stress that some measures actually should be considered to become common practise in turbine design and construction, such as turbine lighting regimes and bird-friendly micro-siting of turbines.

Finally, a prerequisite for successful mitigation is to map baseline information, and doing research on the vulnerable species as a part of the mitigation project [14,17,87,88]. Monitoring of fatalities is especially important, employing a scientifically defensible monitoring method [14,18,86,88,97,169–171].

Acknowledgements

This review was done as part of the project "INnovative Tools to reduce Avian Collisions with wind Turbines" (INTACT). This project was financed by the wind industry (Statkraft, Vattenfall, Statoil, TrønderEnergi Kraft, EnergiNorge) and the Norwegian Water Resources and Energy Directorate (grant number 226241). We are appreciative of their support enabling this work.

Appendix A. Supplementary information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.rser.2014.10.002

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EXHIBIT 13

Mammalian Biology 87 (2017) 125–129

Contents lists available at ScienceDirect

Mammalian Biology

journal homepage: www.elsevier.com/locate/mambio

Short communication

When the excrement hits the fan: Fecal surveys reveal species-specific bat activity at wind turbines

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ARTICLE INFO

Article history:
Received 5 June 2017
Accepted 8 August 2017
Handled by Danilo Russo
Available online 19 August 2017

Keywords:
Attraction
Bat-wind turbine interactions
DNA barcoding
Roosting
Wind energy

ABSTRACT

The reasons why bats are coming into contact with wind turbines are not yet well understood. One hypothesis is that bats are attracted to wind turbines and this attraction may be because bats perceive or misperceive the turbines to provide a resource, such as a foraging or roosting site. During post-construction fatality searches at a wind energy facility in the southern Great Plains, U.S., we discovered bat feces near the base of a wind turbine tower, which led us to hypothesize that bats were actively roosting and/or foraging at turbines. Thus over 2 consecutive years, we conducted systematic searches for bat feces on turbines at this site. We collected 72 bat fecal samples from turbines and successfully extracted DNA from 56 samples. All 6 bat species known to be in the area were confirmed and the majority (59%) were identified as *Lasiurus borealis*; a species that also comprised the majority of the fatalities (60%) recorded at the site. The presence of bat feces provides further evidence that bats were conducting activities in close proximity to wind turbines. Moreover, feces found in areas such as turbine door slats indicated that bats were using turbines as night or foraging roosts, and further provided evidence that bats were active near the turbines. Future research should therefore aim to identify those features of wind turbines that bats perceive or misperceive as a resource, which in turn may lead to new minimization strategies that effectively reduce bat fatalities at wind farms.

As the demand for renewable energy has grown, it has led to the rapid installation of wind power facilities worldwide. As a result, many utility-scale wind farms became operational before it was apparent that wind turbines could have a negative impact on bats (Arnett and Baerwald, 2013). Subsequently there have been reports of bat fatalities, many of which represent multiple mortality events, from operational wind facilities globally (O'Shea et al., 2016; Chou et al., 2017). The majority of these mortality events appear to involve highly mobile or migratory bat species that cover a large geographic range (Arnett and Baerwald, 2013; Lehnert et al., 2014; Roscioni et al., 2014) and can potentially be impacted by the cumulative effects of multiple wind farms (Roscioni et al., 2013). With continued wind energy expansion, there are increasing concerns that there could be population-level implications for bats (O'Shea et al., 2016; Frick et al., 2017).

Thus, understanding why bats are coming into contact with wind turbines is crucial if we are to implement minimization strategies that effectively reduce bat fatalities. One hypothesis proposed by Cryan and Barclay (2009) is that bat fatalities occur because bats are attracted to wind turbines. By identifying the source of the bats' attraction we could potentially devise more targeted minimization strategies that limit bat activity in proximity to wind turbines, which in turn would reduce bat fatalities. A possible explanation for why bats may be attracted to wind turbines is that the turbines themselves provide a resource(s) for bats, such as foraging, mating, or roosting sites (Horn et al., 2008; Rydell et al., 2016). In support of this rationale, Cryan et al. (2014) suggested that the bat behavior they observed on the leeward side of wind turbines was similar to bat behavior seen at tall trees; structures that would provide bats with roosting, foraging, and mating opportunities. Another study by Long et al. (2011) demonstrated that the light grey color of turbine towers and blades attracted insects, suggesting that wind turbines could serve as a foraging resource that would be attractive to insectivorous bats. Given that wind turbines could potentially provide or be misperceived to provide one or more resources, the next step would be to identify those features of wind turbines that could be attractive to bats. Moreover, as the resource requirements of bats are species-specific, the features of wind turbines that attract bats will likely vary among species (e.g., Ammerman et al., 2011).

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http://dx.doi.org/10.1016/j.mambio.2017.08.003
1616-5047/

For any bat species to be actively roosting and/or foraging at wind turbines, we would expect to find other signs or evidence of use by bats on or around the turbines, not just bat fatalities. For example, there are 3 signs that would indicate that bats are roosting at wind turbines: 1) the presence of roosting bats; 2) the presence of feces within or beneath a suitable roost site; and 3) staining, the brown patches left when bat urine evaporates beneath or on the walls of a roost site (Mitchell-Jones and McLeish, 2004). Furthermore, if bats were to frequently spend time, for example, foraging in close proximity to wind turbines we would expect fecal material to be deposited on the wind turbines and transformers. During post-construction fatality searches at a wind energy facility in the southern Great Plains, U.S., we discovered bat feces on a wind turbine tower. These observations led us to hypothesize that bats were actively roosting and/or foraging at the turbines. Thus over 2 consecutive years, we conducted systematic searches for bat feces around the bases of wind turbine towers at this wind facility to determine if any or all of the 6 bat species known to be in the area were active at turbines.

Our study site was Wolf Ridge Wind, LLC (33°43′53.5″N, 97°24′18.2″W) in the cross timbers and prairies ecoregion of north-central Texas. This facility, owned by NextEra Energy Resources, became operational in October 2008 and consists of 75 1.5-megawatt (MW) General Electric wind turbines (model GE 1.5xle) extended over 48 km^2. The wind turbines have a hub height of 80 m, blade length of 42 m, maximum tip height of 122 m, and are spaced at least 1 ha apart in a general east-west direction across open agricultural land used predominantly for cattle grazing (pastures), native hay harvesting, and winter wheat *Triticum aestivum* cultivation. There is an extensive shrub-woodland along the northern boundary of the wind resource area that leads down to the Red River escarpment. During a 5-year period (2009–2013) in which post-construction fatality monitoring took place at this site, 916 bat carcasses were collected (551 *Lasiurus borealis*, 258 *Lasiurus cinereus*, 3 *Lasionycteris noctivagans*, 22 *Perimyotis subflavus*, 49 *Nycticeius humeralis*, 30 *Tadarida brasiliensis*, and 3 unidentified bats; Bennett and Hale 2014), and species identifications were confirmed using DNA barcoding (Korstian et al., 2016).

From July to November 2011 and April to October 2012, we searched all 75 wind turbines for bat feces. These searches were conducted once a week over 2 consecutive days, in which half the wind turbines were searched the first day and the other half were searched on the second. Searchable areas at the wind turbines were separated into 3 sections: 1) the turbine tower (up to 3 m from the ground), stairs, and associated concrete pad; 2) the turbine door; and 3) the transformer and associated concrete pad. We then divided each of these sections into specific zones, parts, or sides. The turbine tower was divided into 5 zones, comprising four quarters of the turbine tower (i.e., zone 1 started after the stairwell next to the transformer), and the stairwell area leading to the turbine door (zone 5). The turbine door was divided into 4 parts including the door frame and light fixture, door face, and 2 sets of slats in the door face (an upper and lower set). Finally, the transformer next to the turbine tower was divided up by its 4 sides and top.

Searching for bat feces, we slowly walked around each wind turbine and transformer making sure we inspected 1) the door slats and gills of transformers (i.e., sides 1, 2 and 4), 2) the surface of the turbine tower, stairwell, door, light fixture, and flat surfaces of transformers (i.e., side 3 and the top), and 3) all areas with concrete, including the 0.5 m wide concrete pad surface surrounding the base of the turbine tower and 0.25 m wide concrete platform of the transformer. Once found, we placed bat fecal pellets in 1.5 ml plastic tubes and stored them at room temperature.

We extracted DNA from each fecal sample collected using the QIAamp DNA Stool Mini-kit (Qiagen Genomics, Valencia, CA). A negative control was used with each round of extraction to ensure that the extraction reagents used were not contaminated. All extractions were completed in a dedicated extraction AirClean® 600 PCR workstation to minimize contamination and the subsequent polymerase chain reactions (PCR) were conducted in a separate dedicated PCR workstation. We employed the DNA barcoding procedure described in Korstian et al. (2015) to identify each fecal sample to species. We reviewed species composition and explored whether there were any trends or species-specific patterns in the locations where fecal samples were found on wind turbines and across the wind facility.

Each of the 75 wind turbines was surveyed 53 times (22 in 2011 and 31 in 2012) for a total of 3975 searches. Fecal samples were found in 29 of the 53 weeks the turbines were searched. We collected a total of 72 bat fecal samples from the surfaces of turbines, transformers and associated concrete pad. The most samples per month were found in July in 2011 (n = 24) and May and June in 2012 (n = 13 and n = 16, respectively), while all other months had <10 samples. DNA was successfully extracted from 56 of these samples (i.e., 78%). The DNA in the remaining 16 bat fecal samples was found to be degraded and could not be processed successfully to identify species.

Among the samples that were identified to species, all 6 bat species known to be in the wind resource area were confirmed: *Lasiurus borealis* (n = 33 samples), *Lasiurus cinereus* (n = 4 samples), *Lasionycteris noctivagans* (n = 2 samples), *Perimyotis subflavus* (n = 7 samples), *Nycticeius humeralis* (n = 9 samples), and *Tadarida brasiliensis* (n = 1 sample). Fecal samples from *Lasiurus borealis* comprised the majority (59%) of the 56 samples.

We found bat feces in all searched areas of the wind turbines, except for the lower slats of the door (Fig. 1). Nineteen fecal samples (26% of the 72) were collected from between the upper slats of the door, between the gills of the transformer, on the frame beneath the gills of the transformer, and beneath the stairwell on the plastic-covered steel rods anchoring the base of the turbine tower. Note that in order for fecal samples to be in these locations, bats would have to physically be within the structures as it is not possible for wind or water to have moved the feces into such locations. Species composition of the fecal samples in these locations comprised *Lasiurus borealis* (n = 8 samples), *Perimyotis subflavus* (n = 4 samples), *Nycticeius humeralis* (n = 3 samples), *Tadarida brasiliensis* (n = 1 sample), and unknown bats (n = 3 samples).

Of the 75 wind turbines searched, we found bat feces on 41 of them: 20 wind turbines had 1 fecal sample, 13 had 2 samples, 6 had 3 samples, and 2 wind turbines had 4 fecal samples collected from them (Fig. 2). The bat fecal samples were widely distributed on turbines across the wind facility, ranging from wind turbines in close proximity to wooded areas to turbines in open cattle pastures. With regards to species-specific patterns, fecal samples from *Lasiurus borealis* were found throughout the site, whereas fecal samples from *Nycticeius humeralis* appeared to be concentrated in 2 areas, one at the western end of the wind farm and a second towards the center of the wind farm. Fecal samples from *Perimyotis subflavus* were primarily found at turbines near the scrub-woodland area located towards the center of the wind farm. Finally, despite the low number of fecal samples found for *Lasiurus cinereus* and *Lasionycteris noctivagans*, these appeared to be distributed across the wind facility.

The presence of bat feces provides further evidence that bats are conducting activities in close proximity to wind turbines. Furthermore, DNA analysis of the fecal samples confirmed that all 6 bat species known to occur in north-central Texas were active at wind turbines and concurs with fatality data reported at our study site. As expected, the majority of fecal samples were identified as *Lasiurus borealis* (59%), corresponding with the proportion of *Lasiurus borealis* carcasses found in fatality monitoring surveys at the site (60%; Bennett and Hale, 2014).

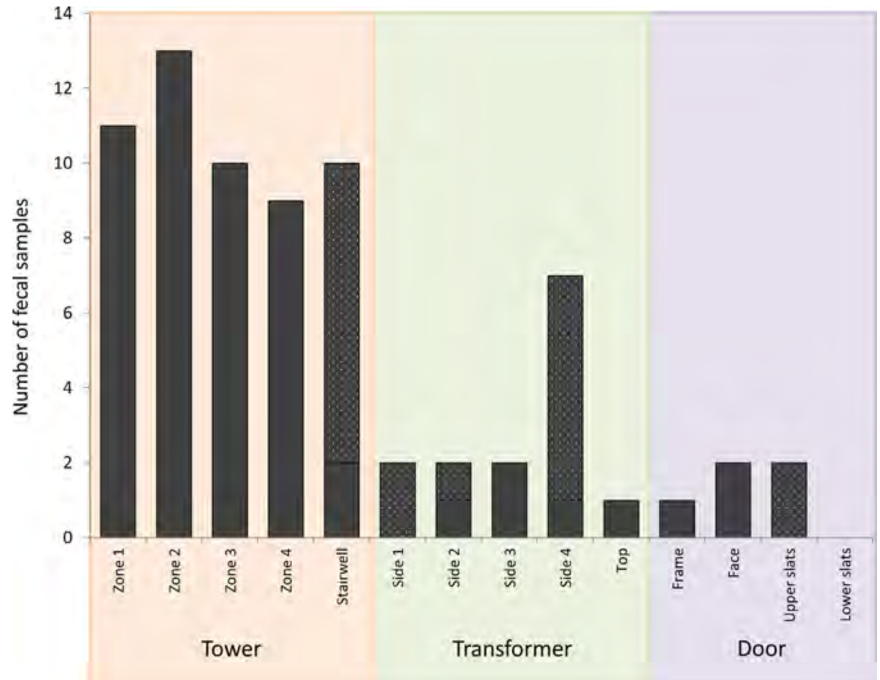

Fig. 1. Number of bat fecal samples collected from searchable locations on wind turbine towers, transformers, and doors at Wolf Ridge Wind, LLC in north-central Texas. Solid color represents fecal samples that were collected from wind turbine surfaces, whereas dots identify feces that were found in structures associated with wind turbines, such as between the slats in the door.

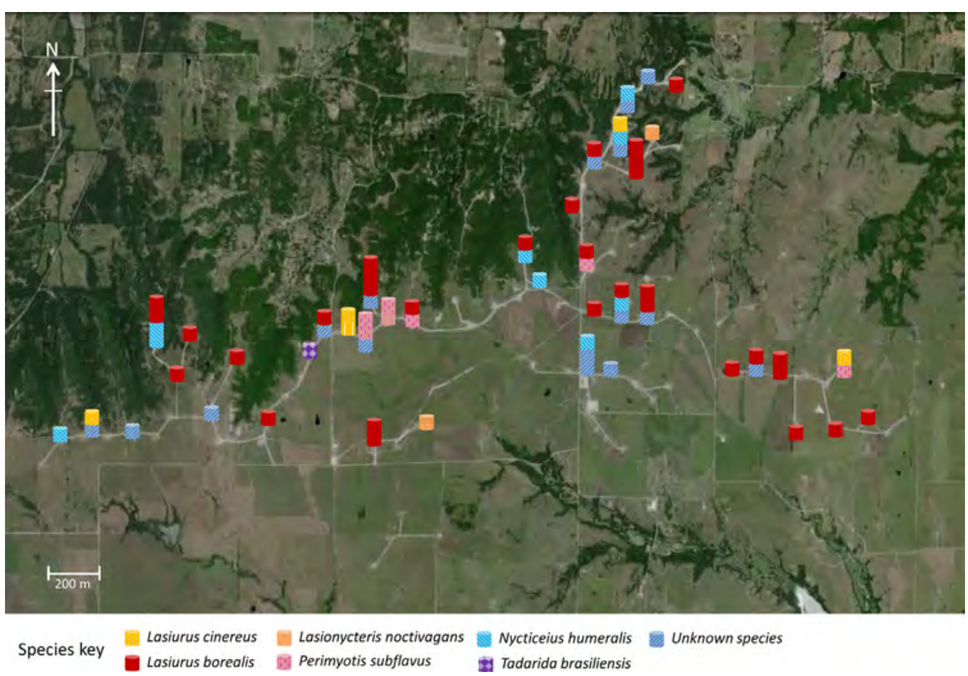

Fig. 2. Number of bat fecal samples by species found on wind turbines at Wolf Ridge Wind, LLC in north-central Texas.

Our findings appear to support the attraction hypothesis and contribute to the mounting evidence that bats are conducting activities, such as foraging, at wind turbines (Horn et al., 2008; Rydell et al., 2016). As bat feces are small (<5 mm in length) and relatively light weight, the likelihood that pellets will be deposited onto searchable areas of a wind turbine is inevitably very low. In addition, there are numerous instances that occur during any given search interval that can remove or destroy feces. For example, over the 2 years we conducted weekly searches, the site experienced rain showers, thunderstorms, and moderate to high winds on a regular basis. The consequence of these events ultimately reduced our ability to successfully locate and collect fecal samples. Furthermore, the ecology of each bat species can also influence our ability to find feces. For example, 3 of the species identified in this study, *Lasiurus cinereus*, *Lasionycteris noctivagans*, and *Tadarida brasiliensis*, are known to forage at greater heights (i.e. above tree canopy height) than *Lasiurus borealis*, *Perimyotis subflavus*, and *Nycticeius humeralis* (Ammerman et al., 2011). Again, the higher bats fly, the less likely fecal pellets will be deposited onto the searchable areas of the wind turbines. Thus, as we were able to retrieve 72 fecal samples during our surveys, including feces from the 3 high-flying bats, it is a testament to the amount of bat activity that occurs in close proximity to wind turbines. In other words, it indicates that bats, in particular *Lasiurus borealis*, the species most frequently found in fatality searches at this site, are active at wind turbines (Bennett and Hale, 2014).

Moreover, the location of bat feces may indicate bats are using wind turbines as roost sites. We found fecal pellets in between the upper slats of the door, between and beneath the gills of the transformer, and on rods under the stairwell; an indication that bats were likely hanging in or above these areas. For most insectivorous bats, there are 2 general types of roost site: 1) day roosts and 2) night or feeding roosts. Day roosts, as the name suggests, are used by bats during the day and their purpose is to protect bats (and potentially their young) from exposure to the elements (i.e., inclement weather conditions, sunlight, and overheating) and from predators (Agosta et al., 2005; Knight and Jones, 2009). Given that the aforementioned areas from which we collected bat feces do not offer protection from the elements, it is more likely that these areas act as night roosts. Night or feeding roosts can be more exposed, as bats use these sites to simply hang and digest food between successive foraging bouts at night (Agosta et al., 2005; Knight and Jones, 2009). Thus, the slats of the doors, gills of the transformer, and the area under the stairwell all represent suitable night roosting opportunities. Furthermore, behavioral surveys using night vision technology undertaken by McAlexander (2013) noted 5 instances over 80 survey nights in which bats were observed entering or exiting the slats of doors or gills of the transformers where the bats remained beyond the length of the survey trial (10 min) or had been prior to the start of the survey trial, respectively. These observations appear to support our findings that bats are using these structures as night roosts. In contrast, over a 5-year period in which standardized fatality monitoring surveys were conducted every other day during the bat activity season (July–September), we also searched the turbine door, stairwell, and gills of the transformer for live bats. Among these fatality monitoring surveys along with the two years of fecal surveys, we only reported the presence of live bats on a turbine once (V.J. Bennett and A.M. Hale, Texas Christian University, unpublished data). On this occasion, 4 *Tadarida brasiliensis* were found in the upper slats of the door and immediately flew away as we approached the turbine door. Note we also found 2 additional *Tadarida brasiliensis* fatalities at this turbine during that fatality monitoring survey not far from the stairwell. As *Tadarida brasiliensis* only make up a small proportion of the fatalities at our site, we considered this finding to be an unusual event. Thus, if indeed bats were effectively able to use wind turbines as day roosts, we would likely have more observations of bats roosting in wind turbines at our site during the day.

Finally, we found that the distribution of fecal samples from wind turbines across the wind facility varied by species. For example, fecal samples from *Lasiurus borealis* were collected at wind turbines in areas that had available resources such as scrub-woodland, and from areas that provided little or no obvious resources (i.e., wind turbines located in open agricultural fields). In contrast, for species such as *Perimyotis subflavus* and *Nycticeius humeralis*, fecal samples were more frequently collected from wind turbines near areas with potential resources (i.e., the scrub-woodland habitat). These observations in all three species also concur with patterns in species-specific fatalities recorded at our site, thus demonstrating that the locations of feces, and therefore where bats are active at wind turbines, correspond with bat fatalities.

Our study provides further evidence that bats are active at wind turbines as they appear perceive or misperceive them to provide a resource and may therefore be attracted to the turbines. Future studies should therefore focus on identifying the specific characteristics of wind turbines that underlie these perceptions in bats and determine if it is possible to alter these features so that bats show little or no interest in them. For example, Gorresen et al. (2015) are investigating how to use low-level ultraviolet lighting as a way to help bats discern between wind turbines and trees and Bienz (2015) has been conducting research to develop a texture coating that may be used to prevent bats from potentially perceiving wind turbine towers to be a foraging or water resource. Such information may then be used to devise minimization strategies that can be implemented to limit bat activity at wind turbines, thereby reducing bat fatalities at wind energy facilities.

Acknowledgements

This work was supported by NextEra Energy Resources [grant number 23186]. Thank you for their support of the TCU-NextEra Wind Research Initiative. Additional thanks go to the staff at Wolf Ridge Wind, LLC who were always helpful and supportive. We also thank the Department of Biology and the Institute for Environmental Studies at TCU for technical and logistical support. Finally, we would like to thank the many people who were involved with the project including M. Slattery for making this project possible, D. Cochran and L. Wyatt for helping with field surveys, and A. Schildt and J. Korstian for conducting the genetic lab work that contributed to our findings.

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EXHIBIT
14

BRIEF COMMUNICATION
https://doi.org/10.1038/s41559-018-0707-z
nature ecology & evolution

Wind farms have cascading impacts on ecosystems across trophic levels

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Wind farms are a cleaner alternative to fossil fuels for mitigating the effects of climate change, but they also have complex ecological consequences. In the biodiversity hotspot of the Western Ghats in India, we find that wind farms reduce the abundance and activity of predatory birds (for example, *Buteo*, *Butastur* and *Elanus* species), which consequently increases the density of lizards, *Sarada superba*. The cascading effects of wind turbines on lizards include changes in behaviour, physiology and morphology that reflect a combination of predator release and density-dependent competition. By adding an effective trophic level to the top of food webs, we find that wind farms have emerging impacts that are greatly underestimated. There is thus a strong need for an ecosystem-wide view when aligning green-energy goals with environment protection.

Wind energy is the fastest-growing renewable energy sector in the world, with current capacity estimates at ~500,000 MW per year (4% of global energy demand)[1,2]. With land requirement of as high as 34 hectares MW^{-1}, close to 17 million hectares of land is currently used for wind energy generation worldwide[3]. Despite the benefits of this renewable energy production, wind farms have ecological costs[4]. Wind turbines cause high mortality in birds and bats from direct impacts[5,6], impede bird migration routes[7], and reduce the density and activity of terrestrial mammals[8,9]. It is often assumed that the greatest impacts of wind turbines are restricted to volant species[9], resulting in significant reduction in local population density (but see ref. [10]). Here, we show that the effects of wind turbines are much larger and are akin to adding an apex predator to natural communities. By reducing the activity of predatory birds in the area, wind turbines effectively create a predation-free environment that causes a cascade of effects on a lower trophic level.

Predator-induced trophic cascades are most apparent in ecosystems where top predators are removed or added, and are often driven by numerical changes in predator densities[11]. Changing predation pressure can affect the local density of prey through direct consumption[12,13], but predation risk can also cause nonconsumptive effects by altering the behaviour, physiology and morphology of prey that survive[14–18]. Our study area—the lateritic plateaus in the Western Ghats of India—is ecologically unique, with high endemism in flora and fauna[19]. Wind farms here have been functioning for 16–20 years[20]. To detect legacy effects of wind farms on small vertebrates, we used a space-for-time substitution[21] and compared areas with and without wind turbines on the same plateau (Supplementary Fig. 1). Apart from the presence or absence of wind turbines, the habitats of sites with ($n=3$; ~0.5 km^2 each) and without wind turbines ($n=3$; ~0.5 km^2 each) were indistinguishable (Supplementary Figs. 2 and 3, and Fig. 1a,b).

Many studies have demonstrated reduced avian density in areas with wind turbines[22–26], but this in itself would not affect lower trophic levels unless there is a concomitant decrease in predation pressure for prey. Raptors regularly prey on small terrestrial vertebrates and are among the most important diurnal lizard predators in this landscape. We found that both the abundance of predatory birds ($Z=-13.91$, $P<0.001$, Cohen's $d=0.84$; Fig. 1d) and the frequency of predation attempts (dive attacks) by raptors on ground-dwelling prey ($Z=-4.45$, $P<0.001$, Cohen's $d=0.29$; Fig. 1e) were almost four times lower in sites with wind turbines than those without. As expected from reduced predation pressure, the density of the most dominant terrestrial vertebrate species in this ecosystem, the endemic superb fan-throated lizard *Sarada superba* (Fig. 1c) was significantly higher in sites with wind turbines compared with those without ($Z=8.93$, $P<0.001$, Cohen's $d=0.48$; Fig. 1f).

However, predation is a strong selective force and terrestrial lizards in sites with wind turbines showed differences in physiology, behaviour and even morphology that were consistent with the nonconsumptive effects of predator release[14,17,18]. Signatures of reduced predation pressure in sites with wind turbines compared with those without were detected in the lower stress-induced ($t=-2.61$, $P=0.05$, Cohen's $d=0.43$) but not baseline ($t=-0.76$, $P=0.48$) levels of circulating corticosterone in free-ranging *S. superba* (Fig. 2a). Physiological stress coping strategies, especially those mediated by the steroid hormone corticosterone, are sensitive to changes in predation pressure and play a vital role in influencing energy mobilization, as well as behavioural and cognitive processes[27]. In some terrestrial mammals, proximity to wind turbines causes an increase in glucocorticoid levels[9,28], presumably because of the stress and interference induced by mechanical noise and infrasound. In contrast with these findings, the downregulation of the hypothalamus–pituitary–adrenal axis for stress reactivity, but not homoeostatic processes, in lizards from sites with wind turbines, is a good indicator of habituation to an environment with fewer intense (predation) stressors[15]. In response to controlled simulated 'predator attacks' by an approaching human, lizards at sites with wind turbines showed significantly lower approach distances ($Z=-5.41$, $P<0.001$, Cohen's $d=0.12$) and flight initiation distances (FIDs) compared with those without ($Z=-5.86$, $P<0.001$, Cohen's $d=0.52$). Lizards from sites with wind turbines had FIDs that were five times shorter than those from sites without, allowing researchers to approach within 3 m before fleeing (Fig. 2b). This reduction in the escape responsiveness of lizards in areas with wind turbines directly follows expectations from the low stress-induced levels of corticosterone[29,30]. The study plateau is used for various anthropogenic activities besides clean energy production; local communities graze livestock and extract non-timber resources. Despite the prevalent human activity in the area, lizards showed relaxed physiological stress responses and

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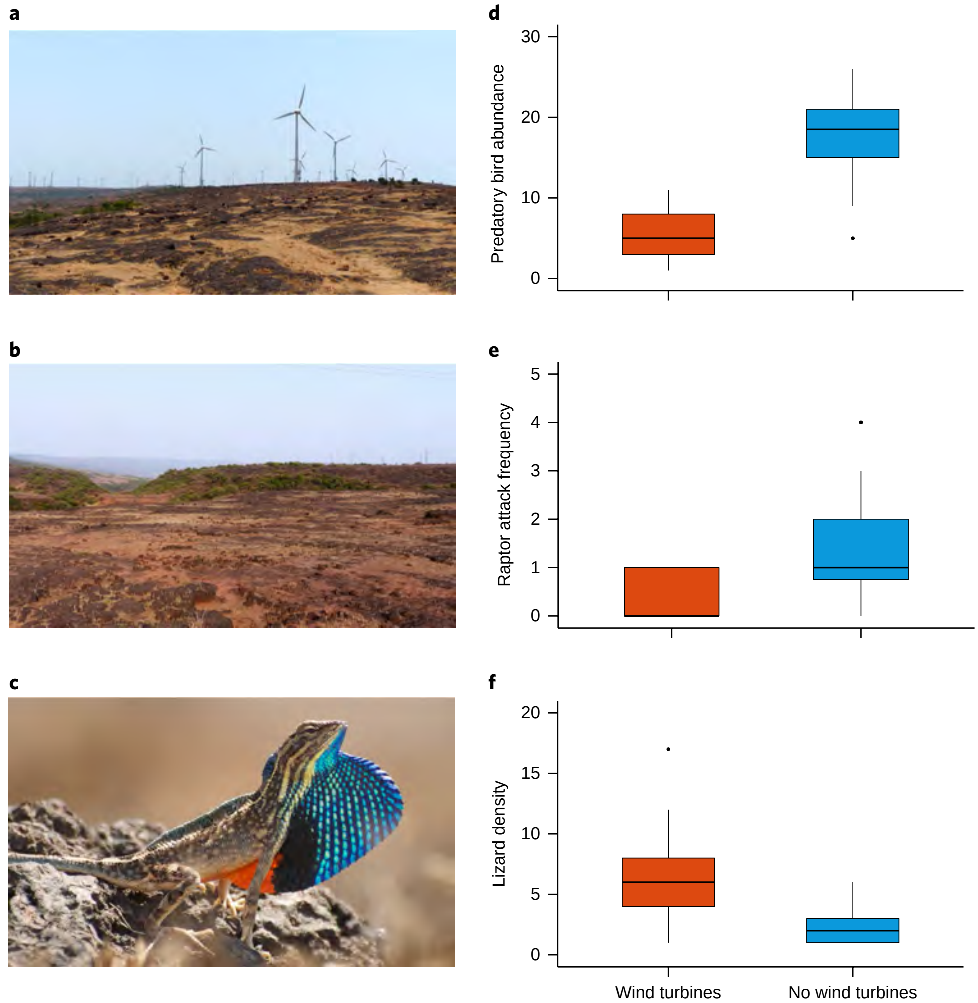

Fig. 1 | Numerical effect of wind turbines on predatory birds and lizard prey. a,**b**, Lateritic habitat on the Chalkewadi plateau (**a**) with ($n=3$ sites) and (**b**) without wind turbines ($n=3$ sites). **c**, The endemic superb fan-throated lizard *S. superba*, which lives on the Chalkewadi plateau. **d**–**f**, Areas with wind turbines (red box plots) had (**d**) a significantly lower abundance of predatory birds (birds per 3 h), (**e**) a significantly lower frequency of raptor attacks on ground-dwelling prey (attacks per 3 h) and (**f**) significantly higher densities of lizards (lizards per 100 m belt transect) compared with areas with no wind turbines (blue box plots). Box plots show the medians, quartiles, 5th and 95th percentiles, and outliers.

anti-predator responses in sites with wind turbines, consistent with the perception of lower predation pressure.

The numerical effects on prey density, as well as shifts in the physiological and behavioural responses to stressors in lizards from sites with wind turbines, are typical effects of predator release on prey in many ecosystems[31]. However, prey can also experience indirect effects of reduced predation pressure mediated through other regulatory mechanisms. Lower predation risk allows for greater foraging opportunities by prey, which can enhance prey growth[32]. However, we found the opposite pattern; free-ranging *S. superba* from sites with wind turbines had lower body condition (that is, they were thinner) than those at sites without (scaled body mass index; $t=24.5$, $P<0.001$, Cohen's $d=0.22$; Fig. 2c). Although we found no differences in habitat or substrate structure, areas with wind turbines may still have lower per-capita food availability (arthropods) because of the higher local lizard densities[33], thereby reducing the body condition of individuals.

Notably, these density-dependent effects in areas with wind turbines not only affected body condition, but also influenced the expression of secondary sexual characteristics. Males of *S. superba* have highly conspicuous blue, black and orange patches on their dewlaps, which are used during inter- and intrasexual communication[34]. We found that males from sites with wind turbines had lower chroma and brightness of the blue (chroma: $t=-3.995$, $P=0.01$, Cohen's $d=0.32$; brightness: $t=-3.40$, $P=0.02$, Cohen's $d=0.23$) and orange (chroma: $t=-2.23$, $P<0.001$, Cohen's $d=0.30$; brightness: $t=-5.40$, $P<0.001$, Cohen's $d=0.30$) patches on their dewlap compared with those from sites without wind turbines (Supplementary Fig. 4). The intensity of colours is a signal of individual quality in many taxa[35]; thus, a reduction in the chroma and brightness of colours in males from areas with wind turbines can have consequences for sexual selection in this population. Sexual ornamentation is known to be enhanced when predation risk decreases[36] and sexual selection increases[37]. Instead, we found that density-dependent competition was a high cost of predator release. High lizard densities under low avian predation risk resulted in greater competition for potentially limiting resources (for example, beetles with high carotenoid content) that are needed to develop enhanced ornamentation.

Wind farms can affect ecological communities in ways that are unexpected and complex. Despite the fact that our study was restricted to a single plateau, we found multiple lines of evidence

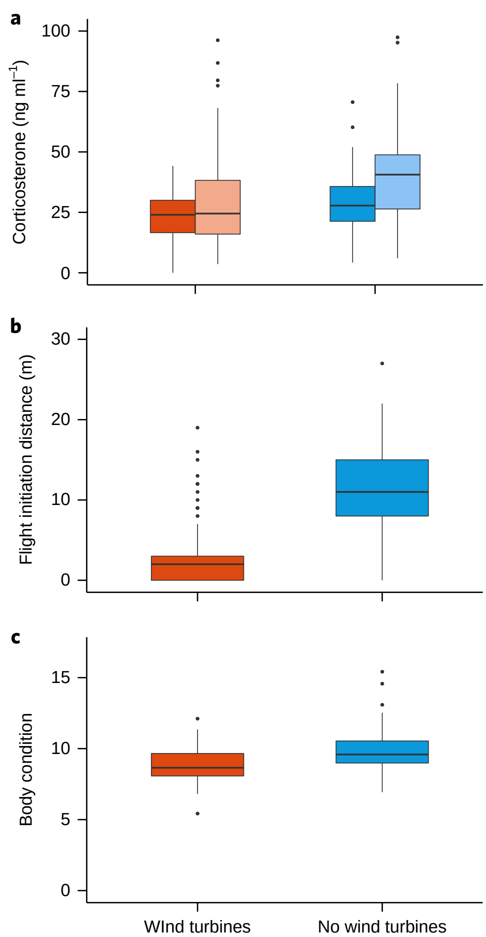

Fig. 2 | The presence of wind turbines influences the phenotypic trait responses of lizards. a–c, *S. superba* from sites with wind turbines (red box plots) had significantly (**a**) lower stress-induced (light box plots), but not baseline (dark box plots), corticosterone levels ($n=81$ from sites with wind turbines; $n=63$ from sites without), (**b**) lower anti-predator responses, as measured by FID ($n=106$ in sites with wind turbines; $n=73$ in sites without) and (**c**) lower body condition, as measured by scaled body mass index ($n=89$ from sites with wind turbines; $n=64$ from sites without) compared with those from sites with no wind turbines (blue box plots). Box plots show the medians, quartiles, 5th and 95th percentiles, and outliers.

for a green-energy-induced trophic cascade. We found that wind turbines do not significantly alter habitat or substrate structure, but they do reduce avian predator abundance and hunting activity (see also refs [23,24]). This large reduction in predator activity lowered the predation pressure for small diurnal terrestrial vertebrates in that area. Numerical changes in prey population size are one of the most conspicuous and rapid consequences of predator release[11]. Consistent with this, we found that densities of the most common lizard species were three times higher in sites with wind turbines compared with those without. We also found strong trait-mediated effects of predator release: lizards at sites with wind turbine not only had lower stress-induced corticosterone levels and anti-predator behavioural responses, but they also had lower body condition and intensity of sexual ornamentation. These population- and individual-level changes in lizards seem to be driven by both the direct (lowered predation pressure) and indirect (increased competition) effects of reduced predation pressure from the top predator guild.

Increasing evidence suggests that humans are an unchecked 'super predator' globally, through their removal of animals[38] and by their induction of fear[39]. Our work shows that even without the direct presence of humans, anthropogenic disturbances such as wind farms act as effective apex predators. By reducing the impact of predatory birds in the area, wind turbines cause a cascade of changes in terrestrial prey, driven primarily by the ecological processes of predator release and density-mediated competition. The loss of apex predators worldwide has resulted in far-reaching consequences for ecosystem processes and stability[11]. Since the locations of wind farms are mainly determined based on economic rather than environmental considerations[40], we stress that the consequences of wind farms are greatly underestimated. While conservation efforts are a necessary global priority, wind farms in unique or biodiverse ecosystems illustrate an unexpected conflict between the goals from the United Nations Paris Agreement[2] for climate change mitigation and Aichi targets from the Convention on Biological Diversity[41].

Methods

Study area. Lateritic plateaus, formed from intense physical and chemical weathering of basaltic rocks, are a unique feature of the northern Western Ghats[19]. These high-altitude (>1,000 m) flat table-topped mountains are characterized by low soil cover and exposed sheet rocks that are mostly devoid of large woody vegetation, giving them a barren appearance. Th s has led to lateritic plateaus being classifi d as 'category 22: barren rocky/stony waste' by the Department of Land Resources, India, even though they support a high diversity of endemic fl ra and fauna[19,20,26]. The unique topographical features of these plateaus, primarily high elevation and absence of large woody vegetation, make them suitable for wind farms. As a consequence, many high-elevation lateritic plateaus in the northern Western Ghats already have wind farms, or are proposed sites for new wind farms[20]. Our study site—the Chalkewadi plateau in Satara district in the northern Western Ghats—has one of the largest and longest-running (~16–20 years) wind farms in the region[20]. Large parts of the Chalkewadi plateau and the adjacent valley lie within the Sahyadri Tiger Reserve and Koyna Wildlife Sanctuary, which are protected and harbour pristine forest habitats[19] (see Supplementary Fig. 1 for a map). These protected areas do not have wind turbines[19,26]. The close spatial proximity of wind farms and undisturbed habitats provides an excellent system for comparison. Although there are no large permanent settlements on the plateau itself, both the eastern and western slopes of the plateau are dotted with several small villages, supporting a substantial pastoralist population. These communities use the plateau as grazing grounds. Hence, there is high human and cattle activity on the plateau, in areas both with and without wind turbines[20].

In this matrix of disturbed habitats (sites with wind turbines) and pristine plateau habitats, we selected six sites (Supplementary Fig. 1): three with wind turbines (13–15 wind turbines in each site) and three without. These sites were approximately 0.5 km^2 in size and about 2 km apart (except 'Enercon' and 'Medha', which were ~1 km apart)—the maximum distance that small-sized agamids (for example, superb fan-throated lizards with a snout-to-vent length (SVL) of <8 cm) are thought to disperse. During the summer months, when this study was conducted, all sites were similar in habitat structure, as determined by a classification of substrate types (see below).

All statistical analyses were done using R statistical software[42]. For all linear and generalized linear models, the model fit was assessed qualitatively, using the distribution of residual versus fitted values, and quantitatively, by comparing small-sample-size-corrected Akaike information criterion (AICc) values of all the competing models. Differences in AICc values (ΔAICc) between the best and second best models are reported for all tests.

Habitat classification. The habitat structure of sites with and without wind turbines was classified at two spatial resolutions. We used remote sensing data with supervised correction methods to classify land-cover types on the entire Chalkewadi plateau into three main categories: (1) rocks/bare ground, (2) vegetation and (3) anthropogenic built-up structures. A satellite image of the plateau containing three bands in the visible-light spectrum (red, blue and green) at a spatial resolution of approximately 5 m for April 2015 was downloaded from an open-source data platform (Bing Maps) and converted into a '.TIFF' format raster before processing in ArcGIS 10.3.1. Pixel reflectance values for bare ground and rocks were indistinguishable and were pooled. We calculated the percentage land cover for each type across the entire plateau and for the individual study areas, and used chi-squared tests to compare the relative proportions of land-cover type between sites with wind turbines and those without. The results from this analysis are reported in Supplementary Fig. 2.

Dry grass is particularly difficult to discriminate from bare ground during the dry summer season using satellite imagery. We therefore also classified substrate types at a finer scale, using sampling plots (1 × 1 m) that we placed randomly at each site ($n=10$ per site; $n=60$ in total) during the peak study period (Supplementary Fig. 3). Plots were photographed with a Canon 5D Mark III and Canon 17–55 mm lens. The open-source image-processing software ImageJ was used to measure the relative proportion of the three dominant substrates: (1) rocks, which included boulders and lateritic sheet rocks; (2) bare ground, characterized as the absence of rocks and vegetation; and (3) vegetation (both green and dry). In most of our plots, vegetation was primarily senescent grasses (Supplementary Fig. 3). For each land-cover type, we ran separate generalized linear mixed models with site as a fixed effect and plot as a random effect with negative binomial distribution. To ensure that the six study sites within areas with and without wind turbines did not differ in substrate, we performed post-hoc Tukey's pairwise comparisons using the 'glht' function in the 'multicomp' package in R. The results from this analysis are reported in Supplementary Fig. 3.

Predation pressure. To determine whether small terrestrial vertebrates such as lizards experience lower predation risk in areas with wind turbines, we estimated the abundance of predatory birds and the frequency of raptor attacks on ground-dwelling prey. Predatory bird abundance was estimated from 500 m time-bound transects ($n=32$ 3 h transects) in areas with and without wind turbines over a period of 8 months from August 2012 to March 2013. We sampled four transects per month on two separate days (one day at the start of the month and another at the end). On each day, H.B. walked two transects (once during the morning from 09:00–12:00 and once in the evening from 16:00–19:00). Hence, we had a total of 96 h of observations for each of our treatments. We classified the birds observed during the transect walks as lizard predators based on information from published bird guides[43,44].

Additionally, to get a more direct measure of predation risk, we conducted point counts over the same 8-month period ($n=32$ sampling events) in areas with and without wind turbines. We followed a sampling protocol similar to the one used to measure bird abundances: we sampled each area four times per month on two separate days (one day at the start of the month and another at the end). Each day involved 3 h of observations in the morning (09:00–12:00) and 3 h in the evening (16:00–19:00). For this measure, we selected a vantage point that provided the best possible 360° view of the area with or without wind turbines, at a larger scale than for the replicate site sampling. H.B. counted the number of times an avian predator dived towards the ground. Predator species that were actively hunting mainly included buzzards (*Buteo* and *Butastur* species), eagles and kites (*Elanus* species). The success of avian predator attacks is difficult to ascertain and thus all attempted attacks were counted. We examined differences in bird abundances using a generalized linear mixed model with Poisson error distribution (ΔAICc = 6.66), with treatment (with or without wind turbines) as a fixed effect and month as a random effect. Similarly, for raptor attack frequency, we ran a generalized linear mixed model with Poisson error distribution (ΔAICc = 3.20), with treatment (with or without wind turbines) as a fixed effect and month as a random effect.

Lizard densities. Study sites were far enough apart to restrict the movement of small territorial diurnal lizards between sites during the study period; thus, we were able to accurately estimate site-level lizard density during the peak activity period. At each of the 6 sites, we marked 100 m × 20 m parallel belt transects that were separated by 100 m. The number of transects per site depended on the size and shape of the site. Belt transect surveys are a widely used method for reptile density estimation[45], and work particularly well for non-cryptic species, such as the fan-throated lizard[46,47]. Two observers (A.Z. and H.B.) walked all transects ($n=10$ transects in each site with wind turbines and 10–16 transects in each site without) during the field season in 2014, and recorded the number and sex of lizards that were observed within 10 m on both sides of the transect line. We alternated sampling between sites with wind turbines and those without across days; thus, sampling was done at a new site with new transect locations on each day (that is, there were no repeated measures of the same transect). The numbers of lizards from all transects at each site were analysed using a generalized linear mixed model with a Poisson error distribution (ΔAICc = 36.76), where treatment (with or without wind turbines) was a fixed effect and site as was a random effect.

Hormonal stress reactivity. To measure hormonal stress reactivity, we quantified corticosterone levels from two blood samples obtained from each lizard ($n=144$ in total). Lizards ($n=29$–32 males from each site with wind turbines; $n=15$–30 males from each site without) were captured by hand and the first blood sample was collected within 3 min of sighting ('baseline'). The stress-induced level of corticosterone was determined from a blood sample obtained 30 min after capture, during which a standardized stress-inducing protocol was implemented where lizards were kept in dark cotton bags[48]. All blood samples were taken within a two-month period during the peak breeding season for the species (April to May 2013), and sites with and without wind turbines were visited on alternate days while sampling. Blood samples (70–100 μl each) were collected from the retro-orbital sinus using a heparinized microhaematocrit tube—a standard sampling method that poses little subsequent risk to individuals[29]. All captured individuals were marked on their ventral side with a permanent non-toxic marker and released at the capture site. Blood samples were stored on ice while in the field. Within 6 h of collection, samples were centrifuged and the isolated plasma was stored in 100% ethanol (1:10 dilution). Corticosterone levels were measured from the plasma samples using enzyme immunoassay kits (DetectX; Arbor Assays) after optimization[49]. Baseline and stress-induced samples were diluted at ratios of 1:20 and 1:40, respectively, and assayed in duplicate across 14 plates. The intra-assay coefficient of variation was 4.81%, based on two standards run with each assay plate, and the interassay coefficient of variation was 5.93%. We ran separate linear mixed models (baseline: ΔAICc = 52.65; stress-induced: ΔAICc = 4.76), with treatment (with or without wind turbines) as a fixed effect and site as a random effect to examine the differences in baseline and stress-induced corticosterone levels.

Anti-predator behaviour. FID is a widely used assessment of anti-predator responsiveness in lizards and other animals[50,51] that directly reflects the economics of fleeing[51,52]. Anti-predator behaviours of lizards were collected between 09:00 and 12:00 from all sites within a single week in April 2014. We alternated sampling between sites with wind turbines and those without on subsequent days, such that each site was sampled once, with no opportunity for habituation to our measurement protocol. We measured FID by approaching male and female lizards from the study sites ($n=31$–43 lizards from each site with wind turbines; $n=15$–34 lizards from each site without) at a constant pace, and recording the distance between the lizard and the researcher when the lizard initiated flight. For all lizards ($n=179$ in total), we also recorded the approach distance as the distance between the lizard and observer when the lizard was first spotted and the approach was initiated. After the lizard initiated flight, approach distances and FIDs were measured with a tape measure (if less than 5 m) or range finder (if greater than 5 m). To determine whether FIDs and approach distances varied between treatments (with or without wind turbines), we ran separate generalized mixed models with negative binomial distribution (FID: ΔAICc = 83.73; approach distance: ΔAICc = 31.93), with treatment and site as fixed and random effects, respectively.

Morphology and colour measurements. We caught a total of 153 males ($n=29$–32 lizards from each site with wind turbines; $n=15$–30 lizards from each site without) by hand and measured their mass and SVL using 10 or 20 g Pesola scales (least count = 0.1 g) and standard rulers (least count = 1 mm), respectively. Mass and SVL data were used to calculate a scaled mass index, which is a measure of body condition[53]. To examine differences in body condition, we ran a linear mixed model (ΔAICc = 124.24), with treatment (with or without wind turbines) as a fixed effect and site as a random effect.

To quantify the magnitude and intensity of sexual colouration on lizards[34], we extended and photographed the dewlap of males ($n=29$–32 lizards from each site with wind turbines; $n=15$–30 lizards from each site without) under full sunlight in the field against a neutral grey standard. We used band ratios to classify dewlaps into 'blue', 'black', 'orange' and 'others' (in C++), and extracted red, green and blue (RGB) values for each patch. A linearization function for the camera, in the form of $y = a \times \exp(b \times x) + c \times \exp(d \times x)$, was derived from a photograph of a colour checker standard (X-Rite) taken under the same conditions. Here, a, b, c and d are empirically derived constants specific to the camera and depend on the response of the camera to known reflectance values of six grey scale standards under specific light conditions[54]. Linearized RGB values were then corrected for possible variation in lighting conditions using grey standards in each of the photographs[54]. We used these linearized and equalized RGB values to derive a two-dimensional representation of the colour space, in which the x axis is the standardized difference between red and green channels, calculated as $(R-G)/(R+G+B)$, and the y axis is the difference between green and blue, calculated as $(G-B)/(R+G+B)$. In this colour space, the distance from the origin is the chroma, calculated as $r=(x^2+y^2)^{1/2}$, and the hue is the angle relative to the axis, calculated as $\Theta=\tan^{-1}(y/x)$[55,56]. Brightness is the sum of the red, green and blue values.

Despite some limitations, we chose the photographic method for colour quantification because it has clear advantages over spectrophotometry, especially for field studies[54,57]. Spectrophotometry only provides point measures of colour with no spatial or topographical information. The standardized photographic method of colour analysis enabled us to obtain multiple measures (hue, chroma and brightness) for all the colour patches on male dewlaps[58]. We compared the chroma and brightness of the two colour patches on males between sites with and without wind turbines using linear mixed effect models (blue chroma: ΔAICc = 14.92; blue brightness: ΔAICc = 9.78; orange chroma: ΔAICc = 7.15; orange brightness: ΔAICc = 31.65), with colour measures as the response variable, and treatment and sites as fixed and random effects, respectively.

Ethical approval. This research was approved by the Institutional Animal Ethics Committee at the Indian Institute of Science (CAF/Ethics/396/2014).

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

The data that support the findings of this study are available from the corresponding author upon request.

Received: 22 April 2018; Accepted: 1 October 2018;
Published online: 5 November 2018

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Acknowledgements

We thank the Maharashtra Forest Department for permits and Suzlon for allowing us to work on their property. We appreciate the logistical support provided by the Bhosale family in Satara, D. Gholap, and the Primary Health Centre in Thoseghar. We also thank N. Dandekar, G. Gowande, D. Joshi and R. Kashid for help in the field, A.K. Nageshkumar for remote sensing analysis, J. Endler for MatLab script, A. Ghatage for help with colour analyses and V. Giri for continued support. The Environmental Science Department of Fergusson College, Pune, provided partial support to H.B. during some of the bird surveys. Funding was provided by the MOEF-CC, DST-FIST and DBT-IISc partnership programme. Finally, we thank S.L. Lima, A.T. Vanak, K. Shanker and A. Batabyal for valuable comments on an earlier version of this manuscript.

Author contributions

M.T. and A.Z. conceived and designed the study, analysed the data and wrote the paper. H.B. conceived and designed the bird data collection. A.Z. and H.B. collected the data. M.T. contributed materials.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information is available for this paper at https://doi.org/10.1038/s41559-018-0707-z.

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Software and code

Policy information about availability of computer code

Data collection	All data were collected in the field by the authors
Data analysis	All data were analysed in R, and we wrote a custom code in C++ to extract color values from digital images of animals.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors/reviewers upon request. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research guidelines for submitting code & software for further information.

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Ecological, evolutionary & environmental sciences study design

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Study description	We conducted a field experiment where we compared multiple parameters in areas with (n=3 WT study areas) and without windturbines (n = 3 NWT study areas). Each study area was approximately 0.5 km2. We controlled for geography by selecting replicate sites on the same plateau where windturbines (main treatment effect) have been in the same locations for at least 16-20 years. All data were collected over two years, in the peak activity season for lizards (March to June). For land-cover measures, we analysed remote sensed data for the entire plateau. For substrate type analysis, we analysed 10 sampling plots (1x1m) in each of the 6 study areas (N=60 plots total). For avian predator abundance, we walked 4 (3 hour long) transects a month for 8 months, where half the transects were in the morning and the other half were in the evening. For raptor predation events, we conducted 32 vantage point counts (3 hour observation periods each) over 8 months. For lizard density measures, we walked 30 belt transects in WT areas and 39 in NWT areas and recorded all lizards seen. Parallel belt transect was 100 m x 20 m each, separated by 100 m. For hormonal stress reactivity, we measured 81 male lizards from WT areas, and 63 male lizards from NWT areas. Two blood samples were taken from each animal (baseline and stress-induced). Antipredator behaviours were measured by approaching 106 lizards in WT areas and 73 lizards in NWT areas and recording escape responses. Gross morphology was measured on 89 male lizards from WT and 64 male lizards from NWT sites. Dewlap colour measurements were taken from 89 males from WT areas and 60 males from NWT areas.
Research sample	Habitat and substrate measures of the study area were taken from remote sensing and on-ground measurements to demonstrate no significant differences between the structure of windturbine and non windturbine areas. Behavioral assays of predation risk was measured by (1) counting the number of avian predators seen, and (2) counting the number of times a raptor (typically Buteo sp., Butastur sp., or Elanus sp.) was seen dive bombing the ground. The rest of the samples were measures of behaviour, morphology and physiology of the superb fan-throated lizard, Sarada superba that live in areas with and without windturbines.
Sampling strategy	For the landscape-level measurement of landcover, we measured the entire study area. Sample size for substrates on the ground were decided based on overall low variability seen on the plateau. Sampling plots were evenly dispersed across each study area (see Supplementary figure 1). Sample sizes for lizards varied based on the measurements. For blood sampling, only lizards caught within 3 min of sighting were included to ensure a baseline measure of corticosterone. Capture of lizards also had to be spread out in space to ensure that capture of one individual did not elevate the stress hormones of neighbouring lizards. A similar spacing protocol was used for the measure of antipredator behaviour so that the "attack" of one individual would not affect the response of nearby individuals. Sample sizes for morphology and dewlap colour were based on the number of lizards that we were permitted to catch based on our research permit and ethics clearance. Lizards used for morphological measurements were also a different subset from the lizards that were sampled for the antirpredator and hormone measures to ensure than prior disturbance by us would not adversely influence the morphology and colour.
Data collection	All data were collected in the field by AZ and HB during the peak activity period of the lizard species. Data was collected continuously and the different measures were taken throughout the sampling season.
Timing and spatial scale	Everyday from March to June on 2013 and 2014
Data exclusions	No collected data were excluded from the analysis.
Reproducibility	These data were generated from field measures and thus could not be examined for experimental reproducibility. Analysis of data from replicate sites within treatments (windturbine vs no-windturbine) show low variance and thus support the fact that within treatment variation is lower than between treatment variation. We include cohen's d for all the statistical analyses.
Randomization	Visit to sampling sites were randomized across days and sampling type (behaviour, morphology, physiology). Care was taken to spread sampling out across space to ensure as much coverage of the environment as possible.
Blinding	Field data on wild caught animals (density, behaviour, morphology) could not be collected blind. Analyses of blood samples and dewlap colour from digital images were conducted blind, with relabeled codes.

Did the study involve field work? ☒ Yes ☐ No

Field work, collection and transport

Field conditions	Rocky lateritic plateau with little vegetation cover. Average temperature during the study season = 34degC (range = 21degC - 45degC). Average precipitation during the study season = 122mm (range =6mm - 152mm). Annual temperature = 26degC and annual precipitation = 91mm
Location	Chalkewadi plateau in the Western Ghats, Mahahastra, India. 17deg36'40"N; 73deg47'27"E

Access and import/export	We have Animal ethics permits from the Indian Institute of Science Animal Ethics Committee and collection/research permits from the state forest department. No import/export permits were required.
Disturbance	Disturbance of the environment was minimal, as most measurements were observational data. And all animals caught were returned to site of capture.

Reporting for specific materials, systems and methods

Materials & experimental systems

n/a	Involved in the study	
☒	☐	Unique biological materials
☒	☐	Antibodies
☒	☐	Eukaryotic cell lines
☒	☐	Palaeontology
☐	☒	Animals and other organisms
☒	☐	Human research participants

Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging

Animals and other organisms

Policy information about studies involving animals; ARRIVE guidelines recommended for reporting animal research

Laboratory animals	none
Wild animals	Several raptor species: only obervational data. Superb fan-throated lizard, Sarada superba. For density estimation and antipredator behaviours, adults were not captured. For morphology, males were captured by hand, measured immediately, and released at site of capture within 30 min. For physiology, males were capture by hand, and were placed in individual cotton bags for up to 30 min before a second blood sample was taken (stress-induced corticosterone measure). While in cloth bags, lizards were kept in the shade. All lizards captured for physiological measurements were released at their exact location of capture within 45 min.
Field-collected samples	Blood samples were stored in microcentrifuge vials in ETOH and kept cool until analysis in the lab.

EXHIBIT

15

International Journal of
*Environmental Research
and Public Health*

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Article

Wind Turbine Noise and Sleep: Pilot Studies on the Influence of Noise Characteristics

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Received: 12 October 2018; Accepted: 15 November 2018; Published: 17 November 2018

Abstract: The number of onshore wind turbines in Europe has greatly increased over recent years, a trend which can be expected to continue. However, the effects of wind turbine noise on long-term health outcomes for residents living near wind farms is largely unknown, although sleep disturbance may be a cause for particular concern. Presented here are two pilot studies with the aim of examining the acoustical properties of wind turbine noise that might be of special relevance regarding effects on sleep. In both pilots, six participants spent five consecutive nights in a sound environment laboratory. During three of the nights, participants were exposed to wind turbine noise with variations in sound pressure level, amplitude modulation strength and frequency, spectral content, turbine rotational frequency and beating behaviour. The impact of noise on sleep was measured using polysomnography and questionnaires. During nights with wind turbine noise there was more frequent awakening, less deep sleep, less continuous N2 sleep and increased subjective disturbance compared to control nights. The findings indicated that amplitude modulation strength, spectral frequency and the presence of strong beats might be of particular importance for adverse sleep effects. The findings will be used in the development of experimental exposures for use in future, larger studies.

Keywords: wind turbine noise; sleep disturbance; experimental study; amplitude modulation; polysomnography

1. Introduction

Wind is a renewable, sustainable source of power. Gross electricity consumption from wind energy in the European Union (EU) member states increased more than threefold between 2004 and 2014, a trend which can be expected to continue in order to fulfil EU climate goals for 2020 [1]. However, with the increase in wind power, more people will consequently live near wind turbines and are at risk of exposure to wind turbine noise (WTN).

According to the World Health Organization (WHO), an estimated 1.0–1.6 million healthy life years are lost each year due to environmental noise in Western Europe alone [2]. Sleep disturbance is the greatest contributor to this loss, accounting for approximately 900,000 years lost annually. Sleep is a physiological state necessary for maintaining mental and physical well-being [3]. Disturbed sleep can have a negative impact on many aspects of health and wellbeing, including impairment of attention [4], memory consolidation [5,6], neuroendocrine and metabolic functions [7,8], mood [9] and overall quality of life [10]. Night-time noise also affects autonomic functions [11,12], and epidemiological studies have demonstrated that long-term exposure to night-time environmental noise may increase the risk for developing cardiovascular disease [13,14].

While sleep disturbance by certain types of environmental noise has been relatively well investigated, particularly transportation noise from rail, air and road traffic [11], there is a relative lack of knowledge regarding the effects of WTN on sleep. Cross-sectional studies in communities with nearby wind farms have demonstrated that WTN causes both annoyance [15–19] and self-reported sleep disturbance [18,19] in a proportion of residents. A recent meta-analysis reported that self-reported high sleep disturbance increased with each A-weighted 10 dB increase in predicted outdoor nocturnal WTN (odds ratio = 1.60, 95% confidence interval: 0.86–2.94) [20]. However, this effect was not statistically significant, and the authors of the meta-analysis concluded that studies with objective measures of sleep and WTN were needed. The results of the meta-analysis were used by the WHO to conclude recently that public health recommendations could not be made for night-time WTN levels, since the quality of evidence was too low [21], assessed via the GRADE approach [22] adopted by the WHO. Low quality evidence in the GRADE approach can be interpreted as "further research being very likely to have an important impact on the certainty of the effect estimate and is likely to change the estimate" [21].

At present, effects of WTN have mainly been evaluated using subjective means, and only a few studies have investigated the physiologic response to WTN during sleep. Using wrist actigraphy, Michaud et al. measured sleep of individuals living 0.25–11.22 km from operational wind turbines to examine whether there was an association between objectively measured sleep disturbance and calculated outdoor WTN levels [23]. They found no consistent relationship between sleep disturbance and sound pressure level (SPL) averaged over one year. In another study, Jalali et al. measured sleep using polysomnography (PSG) in participants' homes, both pre- and post- wind turbine installation and operation [24]. They found no significant differences for any of the measured sleep variables. However, they also did not find any significant differences in SPLs measured in the bedrooms prior to- and after the wind turbines began operating.

Disturbance from noise depends not only on SPL but also on the characteristics of the noise [25]. The main source of noise from modern wind turbines is aerodynamic noise generated when air passes over the rotor blades [26]. Varying wind speed at different locations in the space swept by the rotor blades can lead to an amplitude modulated sound [27], which may be a possible source of disturbance as it is easily perceived and poorly masked by ambient background noise [15]. WTN is also unpredictable as it varies with wind speed and meteorological conditions [28]. Additionally, WTN is not necessarily attenuated during night-time; in fact, WTN levels may increase during stable atmospheric conditions which occur during the night to a greater extent than during daytime [29,30].

When dose-response curves for WTN levels and annoyance have been compared to previously established dose-response curves for other types of environmental noise (industrial and transportation noise), higher proportions of annoyed residents have been found for WTN at equal SPLs [17,31]. It is likely that several factors other than noise level contribute to response, including respondents' general attitude towards wind turbines and the experience of procedural fairness or injustice. Furthermore, one possible source of additional annoyance could be that certain characteristics of WTN are more disturbing [31] than those of other types of environmental noise. It is unclear at present whether such acoustical characteristics of WTN are also of relevance for noise-induced effects on sleep.

Because of the need for further research, we implemented a project named Wind Turbine Noise Effects on Sleep (WiTNES), the primary aim of which is a better understanding of causal links between WTN and sleep impairment. Within the project, a method was developed for synthesising WTN, allowing us to generate WTN with no background noise such as traffic, wildlife or meteorological phenomena, and also allowing for manipulation of different acoustical parameters of the noise [32]. Frequency-dependent outdoor to indoor attenuation curves for WTN level were also developed, allowing us to reproduce WTN spectra for indoor locations such as bedrooms, which is relevant for effects on sleep [33]. The present paper presents two pilot studies investigating the effect of wind turbine noise on physiologically measured sleep, conducted with the intention to guide the design and implementation of a larger-scale main study. Of primary interest was aiding the design of sound exposures for the main study. To our knowledge, these are the first studies investigating the effects of wind turbine noise on sleep under controlled laboratory conditions.

2. Methods

2.1. Experimental Design Overview

Two experimental studies were performed: Study A and Study B. Both studies used a within-subject design, with participants sleeping for five consecutive nights in a sound environment laboratory. Baseline sleep measured during a control night was compared to sleep measured during three nights where participants were exposed to WTN. These exposure nights involved variations of outdoor SPLs and frequency content due to outdoor-indoor filtering, simulating a bedroom with a window being slightly open or closed. Furthermore, within exposure nights there were variations in the acoustic characteristics of WTN.

2.2. Experimental Procedure

In order to make the study environment as ecologically valid as possible, the laboratory was outfitted to resemble a typical apartment, with further details and photographs available elsewhere [34]. It contained a combined kitchen and living area, three separate bedrooms and three lavatories. This allowed three individuals to participate concurrently during a given study period, sharing communal areas but sleeping privately. Each of the bedrooms was furnished with a single bed, a desk, a nightstand, chair and lamps. Low frequency noise (≤125 Hz) was introduced through eighty-eight loudspeakers (Sub-Bass modules, Mod. 4 × 10 in, Jbn Development AB, Örnsköldsvik, Sweden) mounted in the ceilings of the bedrooms. Higher frequencies (>125 Hz) were reproduced via two loudspeaker cabinets in the upper corners of the rooms (C115, frequency response 80–20,000 Hz, Martin Audio, High Wycombe, United Kingdom). Lights out was at 23:00 and an automated alarm in the bedrooms woke the participants at 07:00. To ensure there was sufficient time for PSG electrode placement (see below) and relaxation before going to bed, participants were required to arrive at the laboratory by 20:00 each evening. In order to allow participants to adapt to the unfamiliar environment and the PSG equipment used to measure sleep, the first night was a habituation night without exposure to WTN. Data from this night were not used in the analyses. The second night was an exposure-free control night used to measure baseline sleep. During nights 3–5, participants were exposed to WTN. The order of exposure nights was varied between study weeks, however there were only two study weeks in each of the studies and hence the order of nights was not perfectly counterbalanced. A low background noise (18 dB L_{Aeq}) simulating ventilation noise was played into the bedrooms throughout the study, as otherwise the background level was unnaturally low (≤13 dB L_{AEq}). Questionnaires were completed by study participants within 15 minutes of waking up. To avoid potential confounders that might affect sleep, participants were prohibited from daytime sleeping, caffeine consumption after 15:00 and alcohol consumption at any time during the studies.

2.3. Polysomnography

Sleep can be broadly classified into two states, rapid eye movement (REM) sleep and non-REM (NREM) sleep. NREM is further divided into three stages which are—in order of increasing depth—N1, N2 and N3 [35]. Different sleep stages have different characteristics in the electroencephalogram

(EEG), so we measured physiologic sleep using PSG. We recorded the surface EEG with derivations C3-A2, C4-A1, F3-A2, F4-A1, O1-A2 and O2-A1, electrooculogram and submental electromyogram. Additionally, the electrocardiogram was recorded with two torso electrodes, and pulse, blood oxygen saturation and plethysmogram were recorded using a finger pulse oximeter. Sampling and filter frequencies and placements of electrodes were in line with the American Academy of Sleep Medicine (AASM) guidelines [35]. All data were recorded offline onto an ambulatory PSG device (SOMNOscreen Plus, Somnomedics, Randersacker, Germany). Scoring of the PSG data was performed in line with AASM guidelines [35] by a single experienced sleep technologist who was blind to the study design. EEG arousals, which are abrupt changes in the EEG frequency and sometimes considered indicators of sleep fragmentation [36], were scored as per the American Sleep Disorders Association criteria [37]. Arousals lasting longer than 15 s were classed as awakenings.

Objective sleep variables of interest were sleep onset latency (SOL); total duration and maximum continuous time in stages wake (W), N1, N2, N3 and REM sleep; REM and N3 latency; sleep efficiency (SE); sleep period time (SPT): total sleep time (TST); wakefulness after sleep onset (WASO); timing of first and final awakenings; and the number and frequency of sleep stage changes (SSCs), arousals and awakenings. SOL was the time from lights out until the first non-wake epoch. REM and N3 latencies were the time from sleep onset until the first occurrence of REM or N3 respectively. SPT was the time from sleep onset until the final awakening. WASO was the time spent in W after sleep onset until the final awakening. TST was SPT minus WASO. SE was TST divided by time in bed (TIB, 480 min). SSCs were defined as transitioning from one sleep stage to a lighter stage. Transitions to W were not defined as SSCs but as awakenings. REM sleep was defined as the lightest sleep stage and hence no SSCs could occur from REM. Therefore, SSCs could occur from N3 to N2, N1 or REM, from N2 to N1 or REM and from N1 to REM.

2.4. Questionnaires

In laboratory studies, numerical scales with fixed end points and Likert scales have previously proved capable of detecting the effects of single nights of noise on morning tiredness and perceived sleep quality and depth [38,39], and have been correlated with certain objective sleep measures [40]. Subjective sleep quality was therefore assessed both using an eleven-point numerical scale (anchor points Very poor–Very good) and a five-category Likert scale (Very good; Good; Not particularly good; Poor; Very poor). Nocturnal restoration (anchor points Very tired–Very rested; Very tense–Very relaxed; Very irritated–Very glad) and self-assessed sleep (anchor points Easy to sleep–Difficult to sleep; Better sleep than usual–Worse sleep than usual; Slept deeply–Slept lightly; Never woke–Woke often) were assessed using eleven-point numerical scales.

Questions pertaining to noise-specific effects on sleep were adapted from recommendations for annoyance questions by the International Commission on the Biological Effects of Noise [41]. An eleven-point numerical scale was used to assess how much participants perceived that WTN disturbed their sleep (anchor points Not at all–Extremely) and four five-category Likert scales were used to investigate whether WTN caused poor sleep, wakeups, difficulties falling back to sleep and tiredness in the morning (Not at all, Slightly, Moderately, Very, Extremely). Also included on the questionnaire were items regarding perceived sleep latency, number of awakenings and whether participants found it difficult or easy to fall asleep following awakenings. The complete questionnaire is presented in the Supplemental Methods.

2.5. Noise Exposure: Study A

Following analysis of field measurements of WTN, three eight-hour night-time exposures of WTN were synthesised (hereafter termed Nights A1, A2 and A3) [32,33]. We varied the noise levels to correspond to different outdoor sound pressure levels in the three nights and used different outdoor-indoor filters to simulate the bedroom window being slightly open (window gap) or closed (Table 1). These resulting indoor noise spectra are given in Supplemental Figure S1. To allow investigation of differential effects of different WTN scenarios, eight periods with different sound character, each 400 s in duration, occurred in each hour of each night. Across the eight hours of the night, the ordering of these sound character periods was balanced in a Latin square so that any period would only follow and precede any other period once. Each hour ended with a 400 s period with no WTN. Based on analysis of existing sound characteristics of WTN [32], the noise scenarios differed in SPL, amplitude modulation (AM) strength (3–4 dB, 7–9 dB, 12–14 dB), rotational frequency of the turbine blades, AM frequency bands (low- or middle-frequency) and the presence or absence of strong beats (Table 2). AM is a rhythmic fluctuation in the noise level, and its calculation is described in detail elsewhere [32]. Beats are in this context defined as strong AM in the frequency range 400–2500 Hz. The spectrum for each sound character period is presented in Supplemental Figure S2.

Table 1. Simulated outdoor and indoor sound pressure levels and frequency filtering used in exposure Nights A1, A2 and A3 in Study A.

Exposure Night	$L_{AEq,8h,outdoor}$ (dB)	$L_{AEq,8h,indoor}$ (dB)	Filtering
Night A1	40	29.5	Window gap
Night A2	45	34.1	Window gap
Night A3	50	33.7	Window closed

Indoor levels were measured at the pillow position. $L_{AEq,8h,outdoor}$ = Outdoor A-weighted equivalent noise level over the 8 h night-time period. $L_{AEq,8h,indoor}$ = Indoor A-weighted equivalent noise level over the 8 h night-time period.

Table 2. Overview of the 400 s sound character periods within each hour in Study A.

Period	L_{AEq} Relative to 8-h Level (dB)	Rotational Frequency (rpm)	AM Strength	AM Frequency Band (Hz)	Beats
1	−2.5	15	7–9 dB	500–2000	No
2	-	15	7–9 dB	500–2000	No
3	+2.5	15	7–9 dB	500–2000	No
4	-	13	7–9 dB	80–315	No
5	-	17	12–14 dB	500–2000	Yes
6	-	14	3–4 dB	500–2000	No
7	-	15	12–14 dB	500–2000	No
8	-	18	12–14 dB	500–2000	Yes
9	No WTN				

Sound character was varied in level, turbine rotational frequency, amplitude modulation (AM) strength, AM frequency band and presence or absence of strong beats. Periods 1–8 were counterbalanced across the 8 night-time hours. Period 9 was always the final 400 s of each hour. L_{AEq} = A-weighted equivalent noise level.

2.6. Noise Exposure: Study B

In Study B the noise level, outdoor-indoor filtering and the frequency band of the amplitude modulation were varied between nights (Table 3). These resulting indoor noise spectra are given in Supplemental Figure S3. Within nights, there were variations in AM strength, rotational frequency and the presence or absence of beats. Unlike Study A, each factor had only two levels, giving a 2 × 2 × 2 factorial design, in order to allow comparison between specific sound characters (see Table 4). Each period was 400 s in duration and each hour ended with a WTN-free 400 s period. The periods were presented in a Latin square as described for Study A. The noise spectrum was kept the same for each sound character period, and is given in Supplemental Figure S4.

Table 3. Outdoor and indoor sound pressure levels, frequency filtering and AM frequency bands used in exposure Nights B1, B2 and B3 in Study B.

Exposure Night	$L_{AEq,8h,outdoor}$ (dB)	$L_{AEq,8h,indoor}$ (dB)	Filtering	AM Frequency Band (Hz)
Night B1	45	32.8	Window gap	160–500
Night B2	45	32.8	Window gap	80–315
Night B3	50	30.4	Window closed	80–315

Indoor levels were measured at the pillow position. $L_{AEq,8h,outdoor}$ = Outdoor A-weighted equivalent noise level over the 8 hour night-time period.

Table 4. Overview of the 400 s sound character periods within each hour in Study B.

Period	Rotational Frequency (rpm)	AM Strength	Beats
1	13	3–4 dB	No
2	17	3–4 dB	No
3	13	12–14 dB	No
4	17	12–14 dB	No
5	13	3–4 dB	Yes
6	17	3–4 dB	Yes
7	13	12–14 dB	Yes
8	17	12–14 dB	Yes
9	No WTN		

Sound character was varied in turbine rotational frequency, amplitude modulation (AM) strength, and presence or absence of strong beats. Periods 1–8 were counterbalanced across the 8 night-time hours. Period 9 was always the final 400 s of each hour.

2.7. Participants

For each of the two studies, six young, healthy participants were recruited via public advertising. Participants in study A (4 women, 2 men) had a mean age of 22.2 years, (standard deviation SD $\pm$ 1.3 years) and a mean body mass index (BMI) of 22.6 kgm^{-2} (SD $\pm$ 2.4 kgm^{-2}). Participants in study B (5 women, 1 man) had a mean age of 24.0 years (SD $\pm$ 2.3 years) and a mean BMI of 20.7 kgm^{-2} (SD $\pm$ 0.4 kgm^{-2}). Participants were screened prior to acceptance with the following exclusion criteria: any self-reported sleep-related disorders; sleeping patterns deviating from the intended sleeping hours in the study; tobacco or nicotine use; dependent on caffeine; regular medication affecting sleep; any self-reported hearing disorders including but not limited to hearing loss, tinnitus and hyperacusis. In order to avoid an increased risk of breathing problems or obstructive sleep apnoea among participants, they were required to have a BMI within the normal range (18.5–24.99 kg/m^{-2}). Before acceptance, participants had their hearing tested using pure tone audiometry between 125–8000 Hz to a screening level of 15 dB HL. All participants in both Study A and Study B were classed as being noise sensitive via a single item in the screening questionnaire. All subjects gave their informed consent for inclusion before they participated in the study, and were financially compensated for taking part in the studies. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Gothenburg Regional Ethical Review Board (Dnr 974-14).

2.8. Statistical Analysis

Statistical analyses were performed in SPSS 22 (IBM Corp., Armonk, NY, USA), employing non-parametric methods. Differences between nights were tested using Friedman tests (within-subject), and if a main effect was found then pairwise comparisons were performed using Wilcoxon signed-rank tests. As a pilot, the primary aim of Study A was not hypothesis testing, but rather to inform on the exposures to be used in future, larger studies [42]. Therefore, analyses were restricted to differences between-nights for PSG variables. In Study B, differences across nights for sound character periods 1–9 across nights were additionally analysed. Time in sleep stages N1, N2, N3 and REM were analysed as fractions of TST. To avoid overlooking any potentially relevant outcomes, a significance level of <0.1 was used, and corrections for multiple comparisons were abdicated. All results should therefore be interpreted with this consideration. Median and interquartile range (IQR) values are reported.

3. Results

3.1. Study A: Sleep Micro- and Macro-Structure

Mean values of each PSG variable in each study night are given in Supplemental Table S1. One female participant was excluded from analysis of absolute variables as she woke herself up early following two exposure nights. The ratio of events per hour of TST was analysed for cortical reactions:

SSCs, arousals, awakenings and combined EEG reactions together). There was a significant main effect of the frequency of awakenings (χ^2(df = 3) = 9.0, p = 0.029, Figure 1). Awakenings occurred more frequently during nights with indoor noise levels of 34 dB window closed, Night A3) than in the control night (p = 0.046) and nights with 30 or 34 dB with the window slightly open, (Nights A1 and A2, p = 0.028 and p = 0.028 respectively).

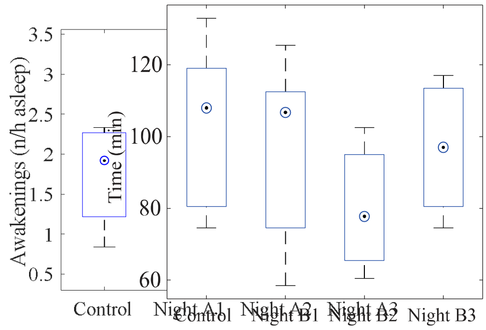

Figure 1. Frequency of awakenings per hour in Study A. Median (◉), interquartile range (boxes) and maximum/minimum values (whiskers).

There were no significant main effects between nights for the frequency of arousals, SSCs or combined EEG reactions, or for measures of sleep macrostructure SOL, N3 latency, WASO, time or maximum continuous time in stages W, N1, N2, N3 or REM.

3.2. Study A: Self-Reported Sleep

There was a significant main effect of perceived sleep disturbance by WTN (Table 5) where, relative to the control night, disturbance was greater in Night A2 (p = 0.042) and Night A3 (p = 0.066). There was also a significant difference in WTN causing tiredness in the morning, with post-hoc tests revealing that Night A3 caused more tiredness in the morning compared to the control night (p = 0.059). No significant main effects were found for any of the variables relating to sleep quality, nocturnal restoration, perceived sleep latency or number of recalled awakenings.

Table 5. Self-reported sleep variables where a main effect of night was found in Study A.

Sleep Measure	Median (IQR)				χ^2	p-Value
	Control	Night A1	Night A2	Night A3		
Sleep disturbance by WTN (0 = Not at all, 10 = Extremely)	0 (0–0.75)	0 (0–2.5)	1.5 (0.75–4)	2.5 (0–4.75)	7.227	0.065
WTN cause tiredness in the morning (Not at all = 1; Extremely = 5)	1 (1–1)	1 (1–2.25)	1 (1–2.25)	2 (1–2.25)	6.400	0.094

IQR = Interquartile range.

3.3. Study B: Sleep Micro- and Macro-Structure

3.3.1. Differences between Nights

Mean values of each PSG variable in each study night are given in Supplemental Table S2. There was a main effect on time spent in N3 (χ^2(df = 3) = 6.310, p = 0.097, Figure 2A), with a significant reduction in N3 sleep in exposure Night B2 compared to the control night (p = 0.043) and Night B3 (p = 0.046). There was a significant main effect of first awakening (χ^2(df = 3) = 9.400, p = 0.024, Figure 2B), with the first awakening occurring earlier in Night B2 compared to Night B1 (p = 0.028) and Night B3 (p = 0.028). There was a main effect of maximum continuous time in stage N2 ($N2_{max}$), (χ^2(df = 3) = 10.200, p = 0.017, Figure 2C), where $N2_{max}$ was shorter in Night B1 (p = 0.027) and Night B3 (p = 0.027) compared to the control night. Furthermore, $N2_{max}$ was shorter in Night B1 (p = 0.046) and Night B3 (p = 0.028) compared to Night B2. No significant main effects were found for SOL, REM or N3 latencies, total number of SSCs, WASO or SPT.

B3 ($p = 0.028$). There was a main effect of maximum continuous time in stage N2 ($N2_{max}$), (χ^2(df = 3) = 10.200, $p = 0.017$, Figure 2C), where $N2_{max}$ was shorter in Night B1 ($p = 0.027$) and Night B3 ($p = 0.027$) compared to the control night. Furthermore, $N2_{max}$ was shorter in Night B1 ($p = 0.046$) and Night B3 ($p = 0.028$) compared to Night B2. No significant main effects were found for SOL, REM or N3 latencies, total number of SSCs, WASO or SPT.

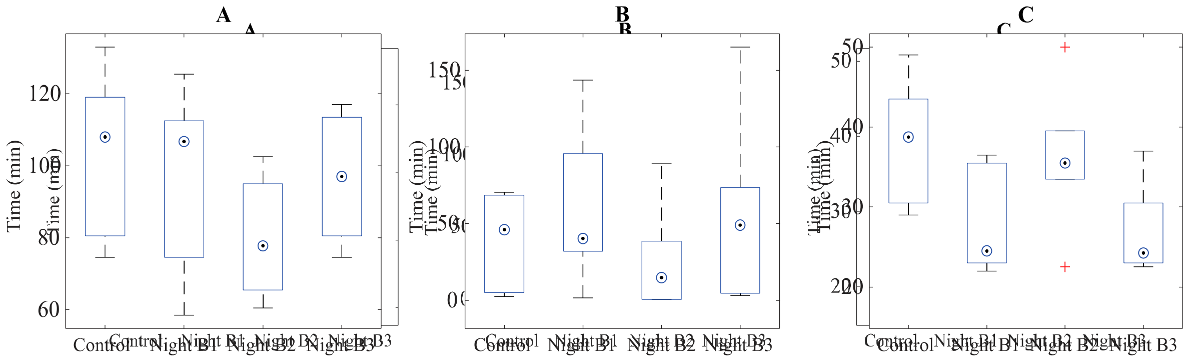

Figure 2. Median (⊙), interquartile range (boxes) and maximum/minimum values (whiskers) for objective sleep parameters from Study B. (**A**) Total time in N3; (**B**) Time between sleep onset and first awakening; (**C**) Maximum continuous time in N2 sleep.

3.3.2. Effects of Sound Character Period between Experimental Nights

Main effects were found for percentage of N1 sleep in Period 6, percentage of N3 sleep in Period 4 and for time awake in Period 3 and 7 (Table 6). Participants spent more time awake in Period 7 in Night B1 ($p = 0.042$) and Night B3 ($p = 0.026$) compared to in the control night. However, post-hoc comparisons revealed no significant between-night differences for time awake in Period 3. The percentage of N1 sleep in Period 6 was higher in Night B2 compared to the control night ($p = 0.028$). There was a higher percentage of N1 sleep in Period 6 in Night B2 compared to the control night ($p = 0.028$). The percentage of N3 sleep in Period 4 was significantly lower in Night B2 compared to the control night ($p = 0.046$), Night B1 ($p = 0.028$) and Night B3 ($p = 0.028$).

Table 6. Objective sleep variables where a main effect of WTN sound character period was found in Study B.

Sleep Measure	Period	Median (IQR) Control	Night B1	Night B2	Night B3	χ^2	p-Value
Time awake (min)	3 [a]	1 (0.50–1.63)	0.75 (0.50–1.25)	1.75 (0.75–5.13)	2 (0.88–2.88)	7.000	0.072
	7 [b]	0.75 (0.38–1.13)	1.75* (1.50–2.0)	1.25 (0.50–2.75)	6.63* (5.74–7.52)	8.509	0.037
N1 (%)	6 [c]	6.63 (5.74–7.52)	6.37 (0.71–13.84)	14.60* (0–15.64)	4.69 (1.81–5.27)	11.400	0.010
N3 (%)	4 [d]	26.77 (21.24–29.41)	29.12 (13.60–33.02)	4.60 *† (0–13.58)	27.22 (18.72–32.89)	10.900	0.014

[a] 13 rpm, strong AM, no beats; [b] 13 rpm, strong AM, beats; [c] 17 rpm, weak AM, beats; [d] 17 rpm, strong AM, no beats. Significant ($p < 0.05$) post-hoc differences to the control night are denoted *. Significant ($p < 0.05$) post-hoc differences to both Night B1 and Night B3 are denoted †. IQR = Interquartile range.

Cortical reaction frequencies (arousals, awakenings and SSCs) were calculated for similar sound character periods and analysed to examine whether any specific sound characteristic was of particular importance (Supplemental Figure S5). There were no significant main effects for arousals ($p = 0.649$), awakenings ($p = 0.197$) or SSCs ($p = 0.191$).

3.3.3. Study B: Self-Reported Sleep

Main effects between-nights were found for tiredness in the morning, tension in the morning, difficulties falling asleep, perceived sleep disturbance due to WTN. Furthermore, main effects were found for whether WTN caused poor sleep, awakenings difficulties falling asleep after awakenings or tiredness in the morning (Table 7).

Table 7. Self-reported sleep variables in Study B.

Sleep Measure	Median (IQR)				χ^2	*p*-Value
	Control	Night B1	Night B2	Night B3		
Sleep quality (Very good = 0, Very poor = 10)	3 (2.75–6.50)	4.5 (2–5.5)	4.5 (1–7.5)	6 (4.25–6.25)	0.911	ns
Verbal sleep quality (Very good = 1, Very poor = 5)	2 (2–2.25)	2 (1.75–4)	2 (1–2.75)	3 (2–3.25)	3.692	ns
Very rested (0)–Very tired (10)	2.5 (1.75–3.25)	5.5 * (1.75–6.25)	2.5 (1.5–6.75)	5.5 * (4–7)	9.367	0.025
Very relaxed (0)–Very tense (10)	3 (2.5–3.5)	4.5 (1–6)	3 (1–4.25)	5.5 *† (4.5–7)	8.625	0.035
Very glad (0)–Very irritated (10)	2 (0.75–4.75)	3.5 (1.75–7)	4 (1–4.5)	5.5 (3.75–6.25)	5.308	ns
Time to fall asleep (min)	15 (8.75–22.5)	27.5 (15.5–38.75)	15 (8.75–46.25)	25 (16.25–42.50)	3.808	ns
Estimated number of wakeups (n)	2 (2–3)	2 (2–4.25)	2.5 (1.75–4)	3 (1.75–3)	0.796	ns
Easy to sleep (0)–Difficult to sleep (10)	3 (0.75–4)	6 * (2.75–8)	2.5 (1–7.25)	6.5 * (4.25–8)	8.793	0.032
Slept better than usual (0)–Worse than usual (10)	5 (4.25–7.25)	6 (4.75–8.25)	5 (2.75–7.5)	7 (6–8.25)	3.982	ns
Deep sleep (0)–Light sleep (10)	3 (2.5–4.25)	6 (2–7.5)	3.5 (1.75–6.75)	6 (3–7.25)	3.911	ns
Never woke (0)–Woke often (10)	6.5 (5–7.25)	4 (2.75–9)	4 (3.25–5)	6 (2.75–7)	0.661	ns
Sleep disturbance by WTN (0 = Not at all, 10 = Extremely)	0 (0–0.25)	2.5 *† (2–7.25)	2.5* (1–4.5)	6 *‡† (3.5–6.25)	14.722	0.002
WTN cause poor sleep (Not at all = 1, Extremely = 5)	1 (1–1)	2 * (1–3.25)	2 (1–3)	3 * (2–3)	10.432	0.015
WTN cause awakenings (Not at all = 1, Extremely = 5)	1 (1–1.25)	1.5 (1–3.25)	1.5 * (1–2.25)	2.5 * (1.75–3.25)	9.250	0.026
WTN cause difficulties falling back to sleep (Not at all = 1, Extremely = 5)	1 (1–1)	2.5 * (1.75–4)	2 * (1.75–2)	3 * (1.75–3.25)	9.889	0.020
WTN cause tiredness in the morning (Not at all = 1, Extremely = 5)	1 (1–1.25)	2 * (2–4)	2 (1.75–3.25)	3 *† (2.75–4)	15.125	0.002

Sleep quality was coded such that the scales are in the same direction as for other items, i.e., a higher value indicates worse sleep. *p*-values relate to tests of main effects. ns = not significant ($\alpha = 0.1$). Significant ($p < 0.1$) post-hoc tests are denoted * (compared to control night); ‡ (compared to Night B1); † (compared to Night B2). IQR = Interquartile range.

Relative to the control, after Night B1 participants were more tired (p = 0.063), had greater difficulty falling asleep (p = 0.072) and were more disturbed by WTN (p = 0.026). In Night B1, WTN-induced poor sleep (p = 0.066), WTN-induced difficulty falling asleep after awakenings (p = 0.041) and WTN-induced tiredness (p = 0.024) were rated deleteriously compared to the control night. Additionally, perceived disturbance from WTN was greater in Night B1 than Night B2 (p = 0.066).

Relative to the control, participants in Night B2 were more disturbed by WTN (p = 0.027) and reported more WTN-induced awakenings (p = 0.083) and WTN-induced difficulty falling asleep after awakenings (p = 0.025).

Relative to the control, participants in Night B3 were more tired (p = 0.026), more tense (p = 0.041), had more difficulty falling asleep (p = 0.027) and were more disturbed by WTN (p = 0.027). Furthermore, they indicated more WTN-induced poor sleep (p = 0.023), more WTN-induced awakenings (p = 0.038), greater WTN-induced difficulty falling asleep after awakenings (p = 0.039) and increased WTN-induced tiredness in the morning (p = 0.024). Furthermore, tension (p = 0.043) and WTN-induced sleep disturbance (p = 0.068) were greater following Night B3 than Night B2. WTN-induced tiredness was higher following Night B3 than Night B1 (p = 0.083) and Night B2 (p = 0.059).

4. Discussion

Two studies investigating the effects of nocturnal wind turbine noise on physiologically measured sleep in a laboratory setting have been presented. They were intended to serve as pilot studies prior to a subsequent larger study, and they had the main objective of providing indications of specific sound character of WTN that may be of particular relevance for effects on sleep. Regarding an overall effect of WTN on sleep, there was some evidence that participants had more frequent awakenings, reduced amounts of N3 ("deep") sleep, reduced continuous N2 sleep, increased self-reported disturbance and WTN-induced morning tiredness in exposure nights with WTN compared to WTN-free nights.

Furthermore, there was limited evidence from Study B that wakefulness was adversely affected by strong amplitude modulation and lower rotational frequencies, N3 sleep seemed to be adversely affected by higher rotational frequency and strong amplitude modulation and N1 sleep increased with high rotational frequency and beating. However, the current analyses have not accounted for potential interaction effects between sound character periods and exposure night. For instance, it cannot be excluded that an interaction between the exposures used in exposure Night B2 in Study B (50 dB outdoor level with a closed window) and the sound characteristics of Period 4 (high RPM, strong AM, no beats) in the same night is responsible for the observed reduction in N3.

Awakenings occur spontaneously during sleep, but an increased awakening frequency can disrupt the biorhythm of sleep, causing sleep fragmentation and often resulting in an increase in wakefulness and stage N1 ("light") sleep with corresponding decreases in deep and REM sleep [38,43]. Deep sleep is believed to be important for nocturnal restoration [44], while N1 may be of little or no recuperative value [45]. Additionally, deep sleep is thought to be important for consolidation of declarative memory, while REM sleep may be important for more implicit memory processes, such as procedural memory [46,47]. While the current studies cannot and do not aim to say anything regarding potential after-effects of the observed changes, the observations of reduced N3, increased N1 and an increased wakefulness under certain sound characteristics of WTN warrants further research.

In Study A, physiologic sleep was generally most impacted during the night with 33.7 dB $L_{AEq,8h,indoor}$ closed window and in Study B by nights with low frequency band AM and 32.8 dB $L_{AEq,8h,indoor}$ slightly open window. Both cases represent experimental nights with the highest or close to highest SPL in the respective studies, although differences to the lowest WTN levels were at most 4 dB. This provides some small support for the level-dependence for WTN-induced sleep disturbance that has sometimes been seen previously in the field for self-reported measures [19]. In both Studies A and B there were however exposure nights with similarly high noise levels where no effects on sleep were seen, although there were also differences in the AM frequency band or spectral content of the noise due to outdoor-indoor filtering. A possible frequency dependency of WTN-induced effects on sleep should be considered in future work.

The studies are limited by both the low sample size, and the representativeness of the study population. The low sample size means that only large effect sizes were likely to be detected, even after relaxing the criterion for statistical significance. The participants, being young and healthy individuals with good normal sleep, are not representative of the typical population that may be exposed to WTN at home. However, considering that the aim was to evaluate whether WTN at these levels could have an impact on sleep and whether certain sound characteristics would have a higher impact, the generalisability to a larger population was not the primary concern. Nevertheless, sleep generally deteriorates with increasing age [48], and the prevalence of sleep-related disorders may be around 27% in field settings [49]. It is therefore plausible that the study population represent a particularly robust group, and any WTN-induced effects on sleep may be worse in the field.

The experimental WTN levels were above the recommended outdoor levels for Sweden [50], although within the recommended outdoor levels for many other countries [51]. The levels were selected to represent worst-case conditions that may occur under unfavourable weather conditions and to increase the likelihood of detecting any effects of WTN despite the low sample size. However, this also means that the findings should not be taken as clear evidence of sleep disturbance due to WTN. The studies were conducted with the aim of providing guidance in the implementation of a larger study, preliminary results of which are available elsewhere [52], and results should be treated accordingly.

5. Conclusions

There were some indications that WTN led to objective sleep disruption, reflected by an increased frequency of awakenings, a reduced proportion of deep sleep and reduced continuous N2 sleep. This corresponded with increased self-reported disturbance. However, there was a high degree of heterogeneity between the two studies presented, precluding firm conclusions regarding effects of WTN on sleep. Furthermore, there was some limited evidence from the second study that wakefulness increase with strong amplitude modulation and lower rotational frequency, the deepest sleep was adversely affected by higher rotational frequency and strong amplitude modulation, and light sleep increased with high rotational frequency and acoustic beating. These findings will be used in the development of noise exposures for a larger-scale sleep study that will implement more naturalistic WTN and use a more representative study population.

Supplementary Materials: The following are available online at http://www.mdpi.com/1660-4601/15/11/2573/s1. Morning questionnaire. Figure S1: Indoor average spectra across the full 8-hour exposure period for each WTN night in Study A. Figure S2: Outdoor spectrum (40 dB $L_{AEq,8h}$) for each sound character period in Study A. Figure S3: Indoor average spectra across the full 8-hour exposure period for each WTN night in Study B. Figure S4: Outdoor spectrum (45 dB $L_{AEq,8h}$) for each sound character period in Study B. Table S1: Mean and standard deviation (SD) of sleep macro- and micro-structure data for each night in Study A. Table S2: Mean and standard deviation (SD) of sleep macro- and micro-structure data for each night in Study B. Figure S5: Median, interquartile range, maximum/minimum values and outliers for cortical reaction frequency across periods of different character WTN. A) Arousals. B) Awakenings. C) Sleep stage changes.

Author Contributions: K.P.W., M.G.S. and M.Ö. conceived the study. K.P.W., M.Ö., M.G.S. and E.P. designed the experiments. P.T., M.Ö. and J.F. developed the experimental noise exposures. M.G.S. performed the study. J.A.M. and M.G.S. analysed the data. J.A.M. and M.G.S. drafted the manuscript. All authors critically appraised and revised the manuscript.

Funding: This research was funded by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS) grant number 2013-745.

Acknowledgments: We thank Stamatina Kalafata, Hanna Hertzberg, Natalie Bogicevic and Nicholas Lindholm for their assistance in conducting the study.

Conflicts of Interest: The authors declare no conflict of interest.

Glossary

AM	Amplitude modulation. A time-varying increase and decrease in sound pressure level, which can vary for different frequencies of the same sound signal
A-Weighting	Frequency weighting filter applied to a sound measurement to mimic the frequency-dependence of human hearing
dB	Decibel, relative to the threshold of human hearing (2×10^{-5} Pa)
EEG	Electroencephalogram
L_{AEq}	A-weighted equivalent continuous sound pressure level, expressed in decibels. Can be considered the "average" of a time-varying sound pressure level over a specified period
$L_{AEq,8h,indoor}$	A-weighted equivalent continuous indoor sound pressure level over 8 h
$L_{AEq,8h,outdoor}$	A-weighted equivalent continuous outdoor sound pressure level over 8 h
NREM	Non-rapid eye movement
PSG	Polysomnography
SSC	Sleep stage change
REM	Rapid eye movement
WHO	World Health Organization
WTN	Wind turbine noise

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EXHIBIT
16

Environment International 82 (2015) 1–9

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

The effect of wind turbine noise on sleep and quality of life: A systematic review and meta-analysis of observational studies

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ARTICLE INFO

Article history:
Received 16 September 2014
Received in revised form 27 April 2015
Accepted 30 April 2015
Available online 16 May 2015

Keywords:
Wind turbines
Annoyance
Sleep
Quality of life
Systematic review
meta-analysis

ABSTRACT

Noise generated by wind turbines has been reported to affect sleep and quality of life (QOL), but the relationship is unclear. Our objective was to explore the association between wind turbine noise, sleep disturbance and quality of life, using data from published observational studies. We searched Medline, Embase, Global Health and Google Scholar databases. No language restrictions were imposed. Hand searches of bibliography of retrieved full texts were also conducted. The reporting quality of included studies was assessed using the STROBE guidelines. Two reviewers independently determined the eligibility of studies, assessed the quality of included studies, and extracted the data. We included eight studies with a total of 2433 participants. All studies were cross-sectional, and the overall reporting quality was moderate. Meta-analysis of six studies (n = 2364) revealed that the odds of being annoyed is significantly increased by wind turbine noise (OR: 4.08; 95% CI: 2.37 to 7.04; $p < 0.00001$). The odds of sleep disturbance was also significantly increased with greater exposure to wind turbine noise (OR: 2.94; 95% CI: 1.98 to 4.37; $p < 0.00001$). Four studies reported that wind turbine noise significantly interfered with QOL. Further, visual perception of wind turbine generators was associated with greater frequency of reported negative health effects. In conclusion, there is some evidence that exposure to wind turbine noise is associated with increased odds of annoyance and sleep problems. Individual attitudes could influence the type of response to noise from wind turbines. Experimental and observational studies investigating the relationship between wind turbine noise and health are warranted.

1. Introduction

The last few decades have seen governments attempting to decrease greenhouse gas emissions (Olander et al., 2012). This response – to changes in the earth's temperature – has seen the rise of wind power (Leithead, 2007). This alternative energy source, generated by wind turbines, is one tool being employed to generate cleaner energy.

Wind turbine generators (WTGs) are devices that convert wind power into kinetic energy, and are regarded as one of the most important renewable sources of power (Leithead, 2007). Energy generated from WTGs can be used to produce electricity and drive machinery (Caduff et al., 2012; Chang Chien et al., 2011; Li and Chen, 2008). It is thought that large scale utilization of these devices can improve global climate by extracting energy from the atmosphere and altering the pattern of gaseous flow in the earth's atmosphere (Keith et al., 2004).

More recently, exposure to noise from WTGs has been reported to have negative effects on human health (Jeffery et al., 2013). People living near WTGs have reportedly experienced sleep disturbances and a reduction in the quality of life; it has been suggested that a combination of turbine noise, infrasound (sounds with frequency <20 Hz) and ground currents (stray current from electrical equipment which passes through the earth) could be responsible for these symptoms (Havas and Colling, 2011). Cases of litigation because of the unwanted health effects allegedly caused by the noise from WTGs have been reported both in the UK (Daily Mail, 2011) and the US (Oregon Herald, 2013). Very recently, the UK parliament passed a bill restricting the number, height and location of WTGs in England (UK House of Commons Library, 2015).

Studies investigating the effects of wind turbines on sleep and quality of life in individuals living in their proximity have been conducted. While the findings from a pooled meta-analyses of three studies suggested a relationship between exposure to WTG noise and annoyance (Janssen et al., 2011), a more recent review concluded that there was no evidence of a consistent relationship between WTG noise and adverse health effects (Merlin et al., 2013). Therefore, the objective of this systematic review was to explore the association between wind turbine noise, annoyance, sleep and quality of life, and also explore

Abbreviations: WTG, wind turbine generator; ESS, Epworth Sleepiness Scale; PSQI, Pittsburgh Sleep Quality Index.

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http://dx.doi.org/10.1016/j.envint.2015.04.014
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the influence of other moderating factors on these outcomes, using data from published observational studies.

2. Methods

We conducted electronic searches in the following databases: Medline, Embase and Global health. Each database was searched from inception till June 2014. MeSH terms used included wind turbine, wind energy, clean energy, annoyance, sleep, and quality of life (a MEDLINE search strategy is included as a web Appendix 1). We also searched Google Scholar for relevant conference proceedings, and hand searched the bibliography of retrieved full texts. An updated search of the databases was conducted on November 28, 2014. Case–control, cross-sectional, and cohort studies were considered for inclusion. To be included in the review, studies had to report annoyance, sleep or quality of life as outcomes in subjects living in proximity with wind turbines. Studies not comparing participants based on the proximity of their homes to WTGs were excluded. No age, language or time restrictions were imposed. Where necessary, contact with study investigators was made to request additional data.

The reporting quality of included studies was evaluated using a checklist adapted from the STROBE (Strengthening of Reporting of Observational Studies in Epidemiology) guidelines (von Elm et al., 2007). Data was systematically extracted by two reviewers [IJO and JOS] using a piloted spreadsheet of pertinent variables including baseline demographics, study location, distances of homes from wind turbines, SPLs, assessment of exposure and outcome. These were independently cross-checked by two other reviewers [MJT and CJH]. Disagreements were resolved through consensus. Our main outcomes were annoyance, sleep disturbance and quality of life (QOL). We also examined the influence of other background noise, visual perception and socio-economic factors on reported outcomes.

Odds ratios (ORs) were used to measure associations between wind turbine noise and annoyance or sleep disturbance. Using the random-effects model of the software for meta-analyses (Review Manager, Version 5.3 (2011)), we calculated the ORs and 95% confidence intervals (CI) for the studies which had sufficient data for statistical pooling. We used sound pressure level (SPL) reference ranges of $<$40 dB for lower exposure and $>$40 dB for higher exposure to wind turbine noise in the analyses; these limits correspond to the World Health Organisation (WHO) guideline recommendations for indoor community noise levels suitable for night-time sleep (Berglund et al., 1999). Where SPLs were not available, we used the reported near ("near group") and far ("far group") distances from WTGs for high and low SPLs respectively. Subgroup analyses by SPLs or distances from WTGs were used to test the robustness of overall analyses. Sensitivity analyses by meta-analysing studies with larger sample sizes or with higher respondent rates ($\geq$50%) were used to investigate heterogeneity using the I^2 statistic; values of 25%, 50%, and 75% indicated low, medium, and high statistical heterogeneity respectively. Where statistical combination of reported data was considered inappropriate, such data was reported narratively.

2.1. Definitions

For the purpose of this review, annoyance was defined as a constellation of psychosocial and/or psychological symptoms — "feelings of being bothered, exasperation at being interrupted by noise, and symptoms such as headache, fatigue and irritability" (Anonymous, 1977). Sleep disturbance was defined as any interruption of an individual's normal sleep–wake pattern (Cormier, 1990). A change in an individual's quality of life was measured based on their own perceptions, with regard to their own goals, expectations, standards and concerns (WHO, 1997).

3. Results

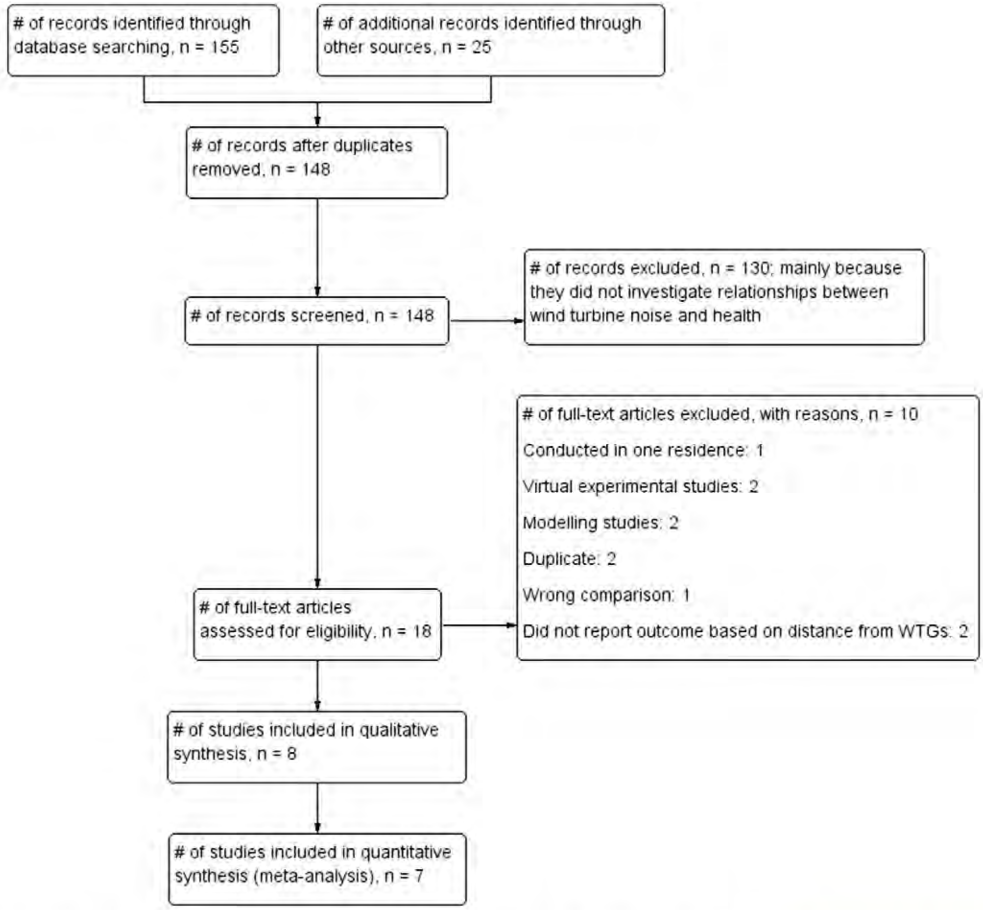
Our electronic searches returned 148 non-duplicate citations, out of which 18 potentially eligible articles were identified (Fig. 1). One article (Ambrose et al., 2012) was excluded because the study was conducted in only one residential apartment and another two (Maffei et al., 2013; Van Renterghem et al., 2013) because they were virtual experimental studies conducted in subjects not residing within the vicinity of WTGs. Two articles (Verheijen et al., 2011; Pedersen and Larsman, 2008) were excluded because they were modelling studies, the latter of which used results from two studies already included in the review. One article was excluded because it explored the effects of road traffic noise using data from a study included in the review (Pedersen et al., 2010) and another two because they did not distinguish subjects by distance from WTGs or SPLs (Harry, 2007; Morris, 2012). Two articles (Nissenbaum et al., 2011; Pedersen et al., 2009) were excluded because more complete versions of their reports were included in the review. Thus eight studies (Bakker et al., 2012; Krogh et al., 2011; Magari et al., 2014; Nissenbaum et al., 2012; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004, 2007; Shepherd et al., 2011) with a total of 2433 participants were included in the review. The key details of the studies are shown in Tables 1, 2a and 2b.

All included studies were of cross-sectional design (Table 1). Seven studies reported appropriate recruitment and sampling strategies, and all used objective and validated measures to compute outcome variables. The studies also used appropriate statistical methods to compare groups, but only half (50%) adequately reported sample size calculations. All studies reported adequate statistical analysis, and baseline demographics for participants in the high and low exposure groups were generally similar. The response rate for questionnaires ranged from 37% to 93%.

Annoyance was measured on a 5-point scale (ranging from did not notice to very annoyed) using questionnaires that enquired about attitudes towards wind turbines; one study (Pawlaczyk-Łuszczyńska et al., 2014) used a 6-point scale that included "extremely annoyed" variable after "very annoyed". In all the studies, annoyance from exposure to WTG noise implied being rather annoyed, very annoyed or extremely annoyed. Sleep disturbance (defined in the studies as interruption of normal sleep patterns) was assessed from the general questionnaire administered in seven studies (Bakker et al., 2012; Krogh et al., 2011; Magari et al., 2014; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004, 2007; Shepherd et al., 2011), and measured by Pittsburgh Sleep Quality Index (PSQI) in the eighth (Nissenbaum et al., 2012) — this same study assessed daytime sleepiness using the Epworth Sleepiness Scale (ESS). Quality of life was measured in three studies by general health questionnaire (GHQ) (Bakker et al., 2012; Pawlaczyk-Łuszczyńska et al., 2014), short form 36 (SF-36v2) (Nissenbaum et al., 2012), and health-related quality of life (HRQOL) (Shepherd et al., 2011). Two studies used unspecified masked questionnaires that addressed health and general well-being (Pedersen and Persson Waye, 2004, 2007); these questionnaires were described as validated. One study (Krogh et al., 2011) did not use a validated questionnaire to assess quality of life and another (Magari et al., 2014) did not report quality of life as an outcome.

The study locations ranged from rural to semi-rural and metropolitan built-up areas (Table 2a), with varying population densities and terrain. The distance of homes from WTGs varied between 0 and 8 km, and the number of WTGs in the individual studies ranged from 16 to 1846. The emission levels for the WTGs in the studies were measured using A-weighted scales (a filtering method aimed at mimicking responses to sound by the human ear) with 8 m/s downwind, and power generated from the turbines ranged between 0.15 and 2300 kW.

The mean age of the respondents across all the studies was 46 to 58 years (Table 2b). One study (Krogh et al., 2011) did not report the socio-economic status of respondents, while another (Bakker et al.,



The Flow Diagram has been adapted from the online version of the PRISMA statement, 2009. Available from: http:// www.prisma-statement.org/statement.htm

Fig. 1. Flow diagram showing the process for inclusion of studies examining the relationship between wind turbine noise and health.

2012) reported a significantly higher proportion of respondent who received higher education in the high SPL group compared with the low SPL group ($p < 0.001$). The remaining studies did not report significant differences in the baseline demographics of respondents. All the respondents in two studies (Magari et al., 2014; Nissenbaum et al., 2012) had financial benefits from WTGs (Table 2b). Reported background noises

Table 1
Reporting quality of studies exploring the association between turbine noise, sleep and quality of life.

Study ID Country of study	Study design	Appropriate recruitment strategy?	Appropriate sampling technique?	Response rate	Representative sample?	Relevant outcome measures?[a]	Power calculation?	Appropriate statistical analysis?	Evidence of bias?
Bakker et al., 2012 The Netherlands	Cross-sectional	Yes — questionnaire sent to houses	Yes	37%	Yes	Yes	Yes	Yes	No
Krogh et al., 2011 Canada	Cross-sectional	Yes — postal & hand-delivered questionnaire	Unclear	88.9%	Yes	Yes	Unclear	Yes	No
Magari et al., 2014 USA	Cross-sectional	Yes — administered in person by two field personnel	Yes	92.9%	Yes	Yes	Unclear	Yes	No
Nissenbaum et al., 2012 USA	Cross-sectional	Yes — telephone and door to door	Yes	40%	Yes	Yes	Unclear	Yes	No
Pawlaczyk-Łuszczyńska et al., 2014 Poland	Cross-sectional	Yes — postal questionnaire	Yes	71%	Yes	Yes	Yes	Yes	No
Pedersen and Persson Waye, 2004 Sweden	Cross-sectional	Yes — questionnaire sent to houses	Yes	68.4%	Yes	Yes	Yes	Yes	No
Pedersen and Persson Waye, 2007 Sweden	Cross-sectional	Yes — postal questionnaire	Yes	57.6%	Yes	Yes	Yes	Yes	No
Shepherd et al., 2011 New Zealand	Cross sectional	Yes — postal	Yes	33%	Yes	Yes	Unclear	Yes	No

[a] All the outcomes measured were subjective, except for Pedersen and Persson Waye (2007) which measured visual perception using visual angle of WTGs from homes.

Table 2a
Main characteristics of studies investigating the association between wind turbine noise, sleep and quality of life.

Study ID	Study location & site topography	Number of participants	SPLs & distance from WTGs	Power & number of WTGs	Outcomes	Tools used to measure outcomes
Bakker et al. (2012)	1. Rural area (with no major road within 500 m from the closest wind turbine) 2. Rural area with a major road within 500 m from the closest wind turbine 3. More densely populated built up area Flat terrain	725	21–54 dB (average: 35 dB) 0–2.5 km	≥500 kW (0.5 MW); 1846	Annoyance, sleep disturbance, psychological stress	Annoyance: 5-point ordinal scale & 2 Likert scales. Sleep disturbance: Frequency
Krogh et al. (2011)	5 WTG areas with anecdotal reports of adverse health effects	109	0.35–2.4 km	1.65 MW: 5 WTG project areas	Sleep disturbance	WindVOiCe Survey Questionnaire
Magari et al. (2014)	1. Rural area 2. 5 receptor locations within wind turbine park; two locations outside the park as comparator	62	0.4–4 km	1.5 MW; 84	Annoyance, health effects	Validated general questionnaire
Nissenbaum et al. (2012)	2 rural areas — 'low-lying, tree-covered island.' Flat terrain	79	32–57 dB 0.4–6.6 km	1.5 MW; 31	Sleep quality, mental health	Sleep disturbance: PSQI & ESS QOL: (SF-36v2)
Pawlaczyk-Łuszczyńska et al. (2014)	1. 3 populated areas in Central & Northwest Poland 2 Flat terrain 3. Mainly agricultural, but railroads and/or roads also present	156	30–50 dB 0.24–2.5 km	0.15, 1.5 & 2 MW; total number of wind turbines 108	Annoyance, mental health	Annoyance: 5-point ordinal scale Sleep and QOL: GHQ
Pedersen and Persson Waye (2004)	5 wind turbine areas; flat terrain	351	<30 to >40 dB 0.15–1.2 km	14 WTGs: 600–650 kW; 2 WTGs: 150 & 500 kW	Noise perception, annoyance, sleep disturbance	Validated general questionnaire: Annoyance: unipolar annoyance scale Sleep disturbance: presence or absence
Pedersen and Persson Waye (2007)	7 wind turbine areas; different landscapes in terrain and urbanisation (flat and 'complex'–rocky or altitude); suburban and rural	754	31.4–38.2 dB (mean: 33.4). 0.6–1 km (mean: 0.78 km)	>500 kW; 478	Perception, annoyance, sleep quality, quality of life	Validated general questionnaire Annoyance: unipolar annoyance scale Sleep disturbance: presence or absence
Shepherd et al. (2011)	2 semi-rural coastal areas differentiated by their proximity to wind turbines; hilly terrain	197	20–50 dB <2 to 8 km	2300 kW; 66	Annoyance, sleep disturbance, quality of life (health)	Questionnaire with subcomponents: Annoyance: 7-item scale Sleep: 7-item scale QOL: HRQOL

Abbreviations: SPLs: sound pressure levels; WTGs: wind turbine generators; dB: decibels; km: kilometres; kW: kilowatts; MW: megawatts; PSQI: Pittsburgh Sleep Quality Index; ESS: Epworth Sleepiness Scale; QOL: quality of life; GHQ: general health questionnaire; HRQOL: health-related quality of life.

included road traffic noise, noises from birds and household pets, and other machinery.

One study (Pedersen and Persson Waye, 2004) was funded by a grant from a research foundation, while four (Bakker et al., 2012; Magari et al., 2014; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2007) were funded by government grants. The authors in two studies (Nissenbaum et al., 2012; Shepherd et al., 2011) failed to declare their sources of funding. The authors in all studies were affiliated with public institutions, except in two studies (Magari et al., 2014; Nissenbaum et al., 2012) where authors were affiliated to public health consultancy firms. One study (Krogh et al., 2011) was not funded by any entity.

3.1. Relationship between wind turbine noise and annoyance

Two studies (Krogh et al., 2011; Nissenbaum et al., 2012) did not report annoyance as an outcome. Meta-analysis of the remaining six studies ($n = 2364$; Fig. 2) revealed a significant increase in the odds of being rather annoyed, annoyed or very annoyed by wind turbine noise (OR: 4.08; 95% CI: 2.37 to 7.04; $I^2 = 63\%$; $p < 0.00001$). Subgroup analyses by SPLs or distance from WTG did not change the direction of the results (Fig. 2). Sensitivity analysis of three studies with larger sample sizes ($n = 1793$) revealed that the odds of being annoyed by wind turbine noise is significantly increased with higher SPLs (OR: 6.94; 95% CI: 4.36 to 11.03; $I^2 = 10\%$; $p < 0.00001$). Meta-analysis of four studies with higher respondent rates ($n = 1313$) revealed that the odds of being annoyed by living close to wind turbines is statistically significant (OR: 3.00; 95% CI: 1.87 to 4.80; $I^2 = 0\%$; $p < 0.00001$).

3.2. Relationship between wind turbine noise and sleep disturbance

Two studies (Nissenbaum et al., 2012; Shepherd et al., 2011) did not provide suitable data for statistical pooling. One of these (Nissenbaum et al., 2012) reported the "near group" as having significantly worse sleep scores for both PSQI ($p = 0.046$) and ESS ($p = 0.03$); and two subjects in the "near group" were diagnosed with insomnia compared to none in the "far group". In the second study (Shepherd et al., 2011), participants with greater exposure to WTG noise reported significantly worse sleep scores ($p = 0.0006$). For the remaining six studies which provided suitable data, three (Bakker et al., 2012; Pedersen and Persson Waye, 2004, 2007) used low SPL values of <30 dB as controls, while two (Krogh et al., 2011; Magari et al., 2014) compared groups based on the distances of respondents' from WTGs. Meta-analysis revealed a significant increase in the odds of reporting sleep disturbances with greater exposure to noise from WTGs (OR 2.94; 95% CI: 1.98 to 4.37; $I^2 = 0\%$; $p < 0.00001$; Fig. 3). Subgroup analysis by SPLs or distance did not result in a change in the direction of the results. A similar result was observed when five studies with higher respondents' rates ($n = 810$) were meta-analysed (OR: 2.76; 95% CI: 1.65 to 4.62; $I^2 = 0\%$; $p = 0.0001$). Sensitivity analyses of studies with larger sample sizes

Table 2b
Demographic characteristics of respondents and influence of moderating factors in the included studies.

Study ID	Mean age	Average duration at home	Socio-economic status	Background noises and their influence on outcome	Visual perception of WTGs and influence on outcome	Financial relationship with WTG and influence on outcome
Bakker et al. (2012)	51 years	Not reported; economic benefits had no statistically significant impact on perception of the sound.	Proportion of respondents with higher education was significantly higher with those living in high SPLs ($p < 0.001$)	Road traffic; aircraft; railways; industry & shunt yards Exposure to WTG sound did not lead to noise annoyance amongst respondents who lived in areas classified as noisy and reported that they could hear the sound. Sound exposure predicted noise annoyance ($r = 0.54$) amongst respondents who reported that they could hear WTG sound and lived in areas classified as quiet	73% of respondents in rural areas and 54% in built-up areas could see at least one WTG from their dwellings The probability of being annoyed by WTG sound was higher if they were visible ($p < 0.001$)	Of 100 persons who benefitted from WTG, 76 were in high SPL group. The proportion of benefiting respondents who were rather or very annoyed by WTG sound was 4 times lower compared to the non-benefiters (12 versus 3%; $p < 0.05$), despite the fact that respondents who benefited economically were exposed to higher levels of WTG sound and noticed the WTG sound more often
Krogh et al. (2011)	52 years	Not reported	Not reported	Not reported	Not reported	Not reported
Magari et al. (2014)	51 years	18 years	Similar for residents	Amongst participants annoyed by WTG noise, 60% were affected daily or a few times weekly by noise, 92% by television or radio interference, and 54% by shadows or reflections None of the indoor or outdoor SPL measurements significantly correlated with other environmental factors — noise, pollution, and landscape littering	On average 19 WTGs were visible General annoyance was significantly correlated with opinion of altered landscape due to WTG ($p < 0.0001$)	All residents benefitted from WTG: substantial property tax reduction; free trash removal Respondents who directly benefitted from WTGs were not less annoyed than other respondents. 90% of participants were satisfied or very satisfied with their environment
Nissenbaum et al. (2012)	57.5 years	14 to 21 years in near group 24 to 30 years in far group	No significant differences	Not reported	WTGs were visible to a majority of respondents The visual impact of WTG on those living closest to turbines was greater compared with those living further away	All residents benefit financially: reduced electricity costs and/or increased tax revenues Fear of reducing property value led to downplaying of adverse health effects
Pawlaczyk-Łuszczyńska et al. (2014)	46 years	Not reported	Comparable between groups	Mainly agricultural terrain with low traffic intensity railways, roads. Did not analyse the impact of terrain and urbanisation on annoyance related to WTG noise. There was high positive correlation between as well as between the respondents' sensitivity to noise and sensitivity to landscape littering ($p < 0.0000001$)	97% of respondents could see 1 or more WTGs from their dwelling, backyard or garden. There was high positive correlation between general attitude towards WTGs and attitude to their visual impact ($p < 0.0000001$)	2.6% benefitted from WTG: type of benefit unspecified
Pedersen and Persson Waye (2004)	48 years	Not reported	No statistically significant differences between groups	Road traffic, rail traffic, neighbours. No significant differences in variables related to noise sensitivity, attitude, or health between the different sound categories At lower sound categories, no respondents were disturbed in their sleep by WTG noise, but 16% of the 128 respondents living at SPLs >35 dB reported sleep disturbance due to WTG noise	WTGs were visible from “many” directions. Respondents' attitude to the visual impact of WTGs on the landscape scenery influenced noise annoyance ($p < 0.001$). No impact of visual perception on sleep disturbance	95% did not own or share a WTG
Pedersen and Persson Waye (2007)	51 years	14 to 16 years in near group 15 to 16 years in far group	Similar for residents	The rural dwellers were the respondents' group with the highest proportion of noise sensitivity (56–59%) There was a significant increase in the odds of annoyance from WTGs in rural areas (quiet) compared with suburban areas (noisy), OR 1.8. [1.25 to 2.51]	The highest proportion of respondents who could see at least 1 WTG was rural (88–91%) Perception of annoyance correlated with SPLs ($p < 0.001$) Both the objective variable “vertical visual angle” and the subjective report of visibility of wind turbines increased the odds of being annoyed: 1.2	Not reported

(continued on next page)

Table 2b (*continued*)

Study ID	Mean age	Average duration at home	Socio-economic status	Background noises and their influence on outcome	Visual perception of WTGs and influence on outcome	Financial relationship with WTG and influence on outcome
					(95% CI: 1.03 to 1.42), and 10.9 (95% CI: 1.46 to 81.92) respectively	
Shepherd et al. (2011)	Range: 18–71 years	Not reported	Matched between groups	No differences between groups for traffic (p = 0.154) or neighbourhood (p = 0.144) noise annoyance	Not reported specifically due to masking of the study intent	Not reported

(n = 838) revealed a significant increase in the odds of sleep disturbances with higher SPLs (OR: 3.24; 95% CI: 2.03 to 5.18; $I^2 = 0\%$; $p < 0.00001$).

Another study (Pedersen and Persson Waye, 2004) reported no statistically significant correlations between sleep quality and sensitivity to WTG noise. One study (Pawlaczyk-Łuszczyńska et al., 2014) reported a significant relationship between the frequency of annoyance and sleep disturbance ($p < 0.05$).

3.3. Relationship between wind turbine noise and quality of life (QOL)

Because of discrepancies in the methods used to assess QOL across studies, a meta-analysis was not considered appropriate. One study (Bakker et al., 2012) reported significant correlations between wind turbine noise and psychological distress in quiet ($p < 0.05$), and both noisy and quiet areas ($p < 0.01$). Another (Nissenbaum et al., 2012) reported that participants in the high noise exposure group had significantly lower QOL (lower GHQ scores) compared with the low exposure group (p = 0.002), and a third (Pawlaczyk-Łuszczyńska et al., 2014) reported a weak but significant correlation between wind turbine noise and mental health based on the responses on the GHQ ($p < 0.00625$) — in the same study, a significantly greater proportion of respondents in the "near group" reported that WTG noise has impacted negatively on their health ($p < 0.05$). Another study (Pedersen and Persson Waye, 2007) reported that SPLs were not correlated with general wellbeing of study participants, but annoyed respondents felt significantly more tired (p = 0.05) and tense ($p < 0.05$) in the mornings. In one study (Shepherd et al., 2011), the high SPL group had lower HRQOL and environmental QOL scores compared with the lower SPL group (p = 0.017 and 0.018 respectively).

One study (Krogh et al., 2011) reported a significant relationship between proximity related WTG noise and excessive tiredness (p = 0.03) (the residents in the groups closer to the WTGs reported a higher percentage of excessive tiredness). This same study showed a trend towards increased risk of headache with closer proximity to WTGs (p = 0.1). Another study (Nissenbaum et al., 2012) reported a near significant increase in the proportion of respondents receiving new psychotropic prescriptions (after WTG installation) in the "near group" compared with the "far group" (24% vs 0.07 p = 0.06). While 90% of participants in one study (Magari et al., 2014) reported being either satisfied or being very satisfied with their environment, the "near group" respondents in another study (Shepherd et al., 2011) were significantly less satisfied compared with the "far group" (p = 0.03).

3.4. Influence of background noise and settings on outcomes

In two studies (Bakker et al., 2012; Pedersen and Persson Waye, 2007), episodes of annoyance at a given WTG noise level were significantly higher in quiet areas compared with areas classified as noisy. A third study (Pedersen and Persson Waye, 2004) reported no significant

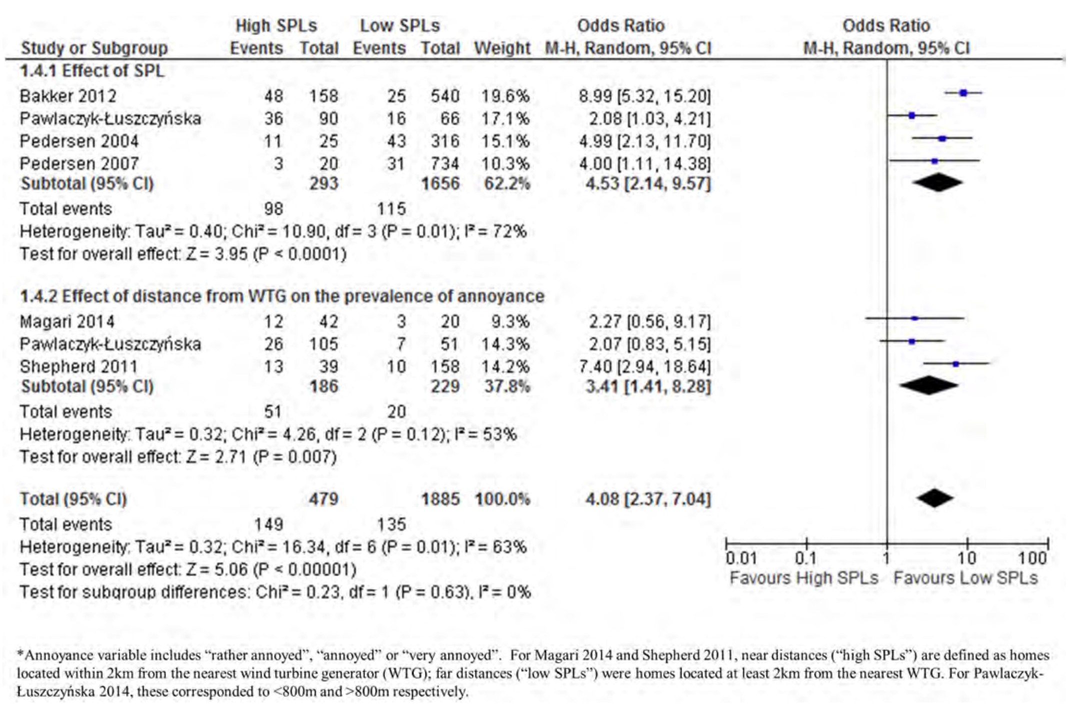
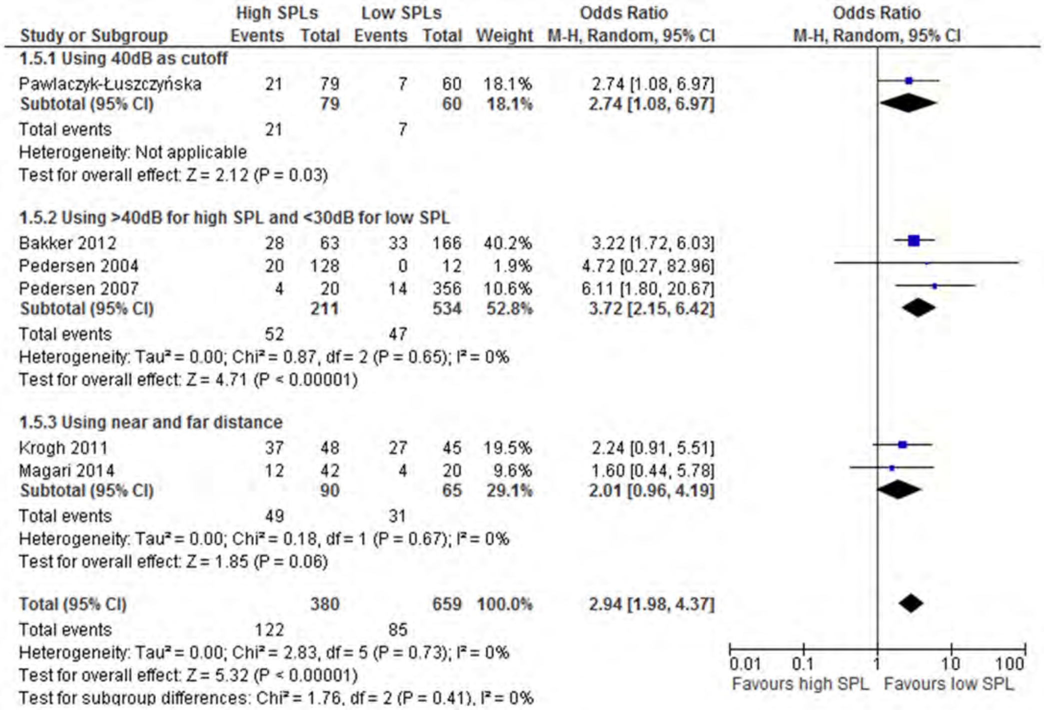


Fig. 2. Relationship between wind turbine noise and annoyance.* *Annoyance variable includes "rather annoyed", "annoyed" or "very annoyed". For Magari et al. (2014) and Shepherd et al. (2011), near distances ("high SPLS") are defined as homes located within 2 km from the nearest wind turbine generator (WTG); far distances ("low SPLS") were homes located at least 2 km from the nearest WTG. For Pawlaczyk-Łuszczyńska et al. (2014), these corresponded to <800 m and >800 m respectively.



*For Magari 2014, near distances ("high SPLs") are defined as homes located within 2km from the nearest WTG; for Krogh 2011, near distances ("high SPLs") were homes located within 700m of the nearest WTG.

Fig. 3. Relationship between wind turbine noise and sleep.* *For Magari et al. (2014), near distances ("high SPLS") are defined as homes located within 2 km from the nearest WTG; for Krogh et al. (2011), near distances ("high SPLS") were homes located within 700 m of the nearest WTG.

difference between groups for different sound categories; however, there was a trend towards increased sleep disturbances with higher SPLs. A fourth study (Shepherd et al., 2011) reported no differences between groups for traffic ($p = 0.15$) or neighbourhood ($p = 0.14$) noise annoyance (Table 2b). One study (Pawlaczyk-Łuszczyńska et al., 2014) did not analyse the impact of other environmental noise on outcomes.

3.5. Effect of visual perception on outcomes

Six studies reported data on the relationship between visual perception of WTG and its influence on outcomes (Table 2b). Five of these (Bakker et al., 2012; Magari et al., 2014; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004, 2007) reported a significant positive correlation between visual perception of WTGs and the episodes of annoyance; one of these studies (Pedersen and Persson Waye, 2007) also reported a significant correlation when an objective variable (visual angle) was used to explore the relationship. The sixth study (Nissenbaum et al., 2012) reported that visual impact of WTG on those living closest to turbines was greater compared with those living further away, but did not report whether this was significant. The authors of one study (Shepherd et al., 2011) did not explore the effect of visual perception on outcomes because they wanted to mask the study intent.

3.6. Influence of economic benefit from WTG on outcome

The influence of economic benefit on outcome was inconsistent across the three studies that explored the relationship. One study (Bakker et al., 2012) reported a significantly lower rate of annoyance amongst respondents who benefitted economically from WTGs compared with respondents who had no benefit ($p < 0.001$), while another study (Magari et al., 2014) reported no significant difference in outcomes between groups. Respondents in the third study (Nissenbaum et al., 2012) indicated that the fear of reducing property value led to downplaying of adverse health effects. Two studies (Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004) in which ≤5% of participants had financial benefits from WTGs did not report whether financial incentives resulted in differences in outcome rates.

4. Discussion

Our results provide evidence that living in areas with WTGs appears to result in "annoyance", and may also be associated with sleep disturbances and decreased quality of life. The results of included studies also suggest that visual perception of WTGs is correlated with increased episodes of annoyance, and the reported adverse effects from WTGs are more prominent in quiet areas compared with noisy ones. The results of our meta-analysis corroborate the findings of a previous meta-analysis of three studies which reported that wind turbine noise is significantly associated with annoyance (Janssen et al., 2011). However, our pooled data contained twice as many studies compared with that report. Our results contradict the findings of another review that concluded that there was no consistent relationship between WTG noise and adverse health effect (Merlin et al., 2013). In contrast to that report, we statistically combined data, and we included evidence from two new studies that were not available for that review. The results of our meta-analysis also support the findings of a more recent systematic review which concluded that exposure to WTG noise increases the risk of annoyance and self-reported sleep disturbance (Schmidt and Klokker, 2014). In comparison with that report, we meta-analysed study data, and also included one study which was not available in that report. Our meta-analyses results should be interpreted with caution due to the variation in outcome measures, and moderate heterogeneity observed in some of the analyses.

The results of our meta-analysis suggest that exposure to WTG noise can elicit annoyance. However, the moderate to large heterogeneity observed in the subgroup analysis limits the firmness of any conclusions that can be drawn from the meta-analytic results. Some authors have suggested that the perception of rhythmic sound pressure by the inner ear could result in negative health outcomes (Enbom and Enbom, 2013; Gohlke et al., 2008; Todd et al., 2008), but this has been refuted by others (Knopper and Ollson, 2011). In addition, other investigators have concluded that it is impossible to distinguish between noises generated by WTGs from that caused by wind itself (Bilski, 2012). Until better tools to assess the impact of WTGs are developed, the relationship between WTG noise and annoyance will remain controversial.

Our meta-analytic results indicate that living close to WTGs increases the odds of experiencing sleep disturbances. Results of studies which did not provide adequate data for statistical pooling were also consistent with this finding. The evidence from the included studies also suggests that sleep disturbance is positively correlated with annoyance and this supports the findings from research conducted in other types of settings (Aasvang et al., 2007; van den Berg et al., 2014; Lee et al., 2011).

We observed a relationship between noise generated from WTGs and reduction in QOL in a majority of the included studies, and this corroborates with previous research reports (Basner et al., 2014; Stansfeld and Matheson, 2003). Pathways showing inter-relationships between annoyance, sleep disturbance and QOL have been modelled (Bakker et al., 2012). However, sleep disturbance has also been shown to independently correlate with a poorer QOL (Lee et al., 2009), and the results of the studies included in our review showed a trend towards a reduction in QOL with increased frequency of sleep disturbances.

It appears that background noise from other environmental sources may influence attitude towards WTGs. The evidence from the studies in our review suggests that the reported adverse effects were more prominent in quiet areas compared with noisy ones. However, residents in quiet areas had a greater proportion of individuals with noise sensitivity and this attitude could have played a role in their responses. Because A-weighted scales (used by most WTGs) totally ignore sound frequencies below 20 Hz, the use of G-weighted scales (specifically designed for infrasound) for measurement of WTG noise has been suggested (Farboud et al., 2013); however, the G-weighted scale has been demonstrated to fluctuate significantly at low frequencies (Bilski, 2012). Other authors have reported that noise from WTGs are too low to cause any harm at distances over 305 m (Knopper and Ollson, 2011; O'Neal et al., 2011). A universally agreed method for measuring sound emissions from WTGs will help clarify these uncertainties.

The results of our review indicate that visual interference could determine attitudes to WTG. There was a greater likelihood of annoyance or less satisfaction if respondents could either see WTGs from their residence, or if they thought WTGs distorted their landscape. This finding supports the conclusions of other authors who reported that visual interference from WTGs may actually be responsible for the annoyance, rather than the noise generated by the wind turbines (Jeffery et al., 2014). Based on this finding, we are less certain if the noise from WTGs themselves actually results in the annoyance, sleep disturbances or reduced quality of life observed in our systematic review and meta-analysis; this issue warrants further investigation.

It is unclear to what extent economic ties with WTGs influenced participants' responses. The inconsistency in the relationship reported across studies makes it difficult to ascertain whether benefitting financially from WTGs affects attitude. Therefore, we are unable to draw conclusions about this relationship based on present evidence.

5. Strengths and limitations

The strengths of this systematic review and meta-analysis are the use of a robust search strategy to identify relevant studies, and our success with obtaining additional data through contact with investigators of studies that we included in the review. The overall quality of the evidence from the included studies was moderate. In addition, heterogeneity was reduced in most of our sensitivity and subgroup analyses, and the results of these analyses were also consistent with overall analyses. However, we recognize some limitations. The small number of included studies prevented us from performing a funnel plot to test for publication bias. It could be argued that publication bias may have occurred in either direction, given the different financial and social implications of WTG and their placement. It is also possible that participants' responses could have been biased; especially in settings where anecdotal reports of adverse effects from WTGs have been documented (Krogh et al., 2011; Magari et al., 2014; Nissenbaum et al., 2012), or in situations where administered questionnaires did not mask the topic of interest (Bakker et al., 2012; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004, 2007). It is difficult to gauge the extent to which residual background noise or financial benefits influenced the responses received from study participants. The variations in topography, design, number and power of WTGs, and variation in outcome measures limit the conclusions that could be drawn from our analyses. Finally, apart from one study (Pedersen and Persson Waye, 2007) which used an objective method (visual angle) to assess the relationship between visual perception and annoyance, the response variables measured in the included studies are all subjective and do not establish causality for the relationships examined.

5.1. Implications for research and policy

Independently funded studies exploring the relationships of wind turbines on human health are warranted; in particular, objective outcome measures that separate auditory and visual effects of WTGs should be developed. Experimental and observational studies investigating the relationship between noise exposure at WTGs and health effects should be conducted. Such studies should also explore whether benefitting economically from WTGs influences attitudes. In addition, research aimed at determining the minimum distance of homes from wind turbines at which there will be no risk of interference with health is advocated.

Further, greater monitoring of the sound emission levels from WTGs, especially those located in quiet rural communities, is advocated. A balance between individual and community preferences should be struck when making decisions about where to site WTGs. This will help to ensure the maximisation of the climatic, provider and consumer benefits from future constructions of WTGs.

6. Conclusion

The evidence from cross-sectional studies suggests that exposure to wind turbine noise may be associated with increased frequency of annoyance and sleep problems. Evidence also suggests that living in proximity to WTGs could be associated with changes in the quality of life. Individual attitudes could influence the type of response to noise from WTGs.

Authors' contribution

IJO and JOS were involved with protocol design, data extraction, data-analysis and interpretation, and co-drafting of the manuscript. MJT was involved with data-analysis and interpretation, and co-drafting of the manuscript. CJH was involved with protocol design, data analysis and interpretation, and co-drafting of the manuscript.

Funding

None.

Competing interest

Professor Heneghan has received payment for running educational courses at the University of Oxford and for external teaching and training. He also receives royalties for books (Evidence Based Toolkit series by Blackwell BMJ Books). Dr Onakpoya, Dr O'Sullivan and Prof. Thompson have no interests to disclose.

Acknowledgement

We would like to thank James Shepherd, Carmen Krogh and Shannon Magari for providing additional information and clarification on their studies.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.envint.2015.04.014.

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EXHIBIT
17

Acoust Aust (2018) 46:31–57
https://doi.org/10.1007/s40857-017-0115-6

REVIEW PAPER

Health Effects Related to Wind Turbine Sound, Including Low-Frequency Sound and Infrasound

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Received: 15 June 2017 / Accepted: 15 September 2017 / Published online: 23 October 2017

Abstract A narrative review of observational and experimental studies was conducted to assess the association between exposure to wind turbine sound and its components and health effects in the general population. Literature databases Scopus, Medline and Embase and additional bibliographic sources such as reference sections of key publications and journal databases were systematically searched for peer-reviewed studies published from 2009 to 2017. For the period until early 2015 only reviews were included, while for the period between January 2015 and January 2017 all relevant publications were screened. Ten reviews and 22 studies met the inclusion criteria. Most studies examined subjective annoyance as the primary outcome, indicating an association between exposure levels and the percentage highly annoyed. Sound from wind turbines leads to a higher percentage of highly annoyed when compared to other sound sources. Annoyance due to aspects, like shadow flicker, the visual (in) appropriateness in the landscape and blinking lights, can add to the noise annoyance. There is no evidence of a specific effect of the low-frequency component nor of infrasound. There are indications that the rhythmic pressure pulses on a building can lead to additional annoyance indoors. Personal characteristics such as noise sensitivity, privacy issues and social acceptance, benefits and attitudes, the local situation and the conditions of planning a wind farm also play a role in reported annoyance. Less data are available to evaluate the effects of wind turbines on sleep and long-term health effects. Sleep disturbance as well as other health effects in the vicinity of wind turbines was found to be related to annoyance, rather than directly to exposure.

Keywords Health effects · Wind turbine sound · Infrasound · Low-frequency noise · Observational studies · Experimental studies

1 Introduction

Globally, the use of sustainable sources of energy such as biomass, water power, solar and wind energy is increasing in order to reduce the use of fossil fuel. Worldwide targets are set for an increase in sustainable energy. As a result, it can be expected that the number of wind farms will keep growing in the years to come and more people will have them in their immediate living environment. Most people have a positive attitude towards alternative energy sources; for example, in the Netherlands in 2006 90% of the population was positive about solar energy and 79%[1] was positive about wind energy. However, although the benefits at national and global level are recognized, viz. a reduction in atmospheric carbon dioxide concentration, at a local level people often oppose wind farm plans. The awareness of the consequences of a wind farm can lead to intense, and sometimes emotional discussions about the need for wind energy, the suitability of the area, the visual and aesthetic aspects and noise-related issues

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are not uncommon. Health effects of living in the vicinity of the turbines are often part of the discussion. The association between wind turbines and human responses is a complex one, and many factors play a role in the public debate. At the local level attention is often focused on the potentially negative health effects of living near a wind turbine.

This paper addresses the state of the art regarding health effects related to wind turbine sound and is based on a manuscript prepared at the request of the Noise and NIR Division of the Swiss Federal Office for the Environment (Bundesamt für Umwelt). Although several excellent reviews on this topic have been published, we think it is worthwhile to publish this narrative review because several large studies have been completed after publication of the most recent meta-analysis [1]. Also, this review addresses the effects to living in the vicinity of wind turbines (WT's) in a broader physical and social context and includes the evidence for possible health effects of the low-frequency and infrasound components. And finally, we made an effort to write a text that is accessible for a broader audience.

In this text we use the word 'sound' when it refers to sound in a neutral sense. The sound of WT's is not always perceived as negative as the word 'noise' (meaning: unwanted sound) would suggest. The term WT noise is quite common but in our opinion only correct when it refers to negative effects, such as in 'noise annoyance'. When it does, we may also use the word 'noise'.

In line with the definition of health as 'a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity' of the World Health Organization (WHO) [2], noise annoyance and sleep disturbance are considered here as health effects [3] [2] [4].

Because this review aims at a broad audience, it might be useful to explain briefly WT sound itself. We therefore start in Sects. 1.1 to 1.3 with an explanation of the sound produced by and heard from a wind turbine and what sound levels occur in practice. After a description of methods used in this review in Sects. 2 and 3 first summarizes the evidence from existing reviews. This is followed by a more detailed description of studies not covered in these reviews. In both parts the key issue is how sound from a wind turbine can affect people, especially neighbouring residents, and in what way and to what degree other factors are important to take into account. This is repeated in Sect. 4 for sound at (very) low frequencies that allegedly can affect people in other ways than 'normal' sound does. Here we use the term 'normal' sound casually when it is easily recognizable as sound and can be heard; this does not include infrasound or low levels of other sound that are normally considered to be inaudible.

Our conclusions from reading and interpreting all the scientific information are summarized in Sect. 5 that concludes the main text.

1.1 Sound Production and Character

An overview of wind turbine sound sources can be found in a number of publications such as [5–8]. For the tall, modern turbines most sound comes from flowing air in contact with the wind turbine blades: aerodynamical sound. The most important contributions are related to the atmospheric turbulence hitting the blades (inflow turbulence sound) and air flowing at the blade surface (trailing edge sound).

- Turbulence at the rear or trailing edge of a blade is generated because the air flow at the blade surface develops into a turbulent layer. The frequency with the highest (audible) sound energy content is usually in the range of a few hundred Hz up to around 1000–2000 Hz. At the blade tips conditions are somewhat different due to air flowing towards the tip, but this tip noise is very similar to trailing edge noise and usually not distinguished as a relevant separate source.
- Inflow turbulence is generated because the blade cuts through turbulent eddies that are present in the inflowing air (wind). This sound has a maximum sound level at around 10 Hz.
- Thickness sound results from the displacement of air by a moving blade and is insignificant for sound production when the air flows smoothly around the blade. However, rapid changes in forces on the blade result in sudden sideways movements of the blade and sound pulses in the infrasound region. This leads to the typical wind turbine sound 'signature' of sound level peaks at frequencies between about 1–10 Hz. These peaks cannot be heard, but can be seen in measurements.

Inflow turbulence sound is important in the low- and middle-frequency range, overlapping with trailing edge sound at medium and higher frequencies. As both are highly speed dependent, sound production is high where the speed is high and highest near the fast rotating tips of the blades. Wind turbine sound can sometimes be tonal, i.e. one can hear a specific pitch. This can be mechanical sound from the gear box and other devices in the turbine which was a relevant source for early turbines. Another possible source is an irregularity on a blade, but this is apparently rare and can be mended.

When the sound penetrates into a dwelling, the building construction will attenuate the higher frequencies better than the lower frequencies. As a result, indoor levels will be lower and the sound inside is of a lower pitch, as higher frequencies

[2] Although high annoyance is not classified as a disease in the International Classification of Disease (ICD-9; ICD-10), it does affect the well-being of many people and therefore may be considered to be a health effect falling within the WHO definition of health.

are more reduced than low frequencies. This is true for every sound coming from outside. Wind turbine sound changes over time. An important feature is the variation of the sound at the rhythm of the rotating blades. This variation in synchrony with the blade passing frequency is also called the amplitude modulation (AM) of the sound [6,9–12].

1.2 Human Hearing

Most environmental sounds with a level of 40 dBA will approximately have the same loudness for human hearing because the A-weighting (that is implied by the A in dBA) is based on the loudness curve of 40 phon (which equals 40 dB at 1000 Hz). Such a low to moderate loudness is comparable with actual wind turbine sound levels at many residences near wind farms. Therefore, A-weighting should give a (nearly) correct estimate of the loudness of a sound. With hearing tests this was confirmed in the Japanese wind turbine sound study [13]. A-weighting is less correct at lower sound levels; application of A-weighting to low levels (roughly < 30 dBA) may allow for more low-frequency sound. Of course, this concerns sound levels that are already low and usually will comply with limits. It is because of the combination of our hearing capacities at different frequencies and the sound level of the different wind turbine sources that trailing edge sound is the most dominant sound when outside and not too far from a wind turbine. The sound will shift to lower frequencies at larger distances or indoors, and then inflow turbulent sound can be more important.

When a sound is ‘subaudible’, the level of that sound is below the hearing threshold and thus below the level it can be audible. Usually the ‘normal’ threshold (hearing threshold of young adults without hearing problems, according to the international standard ISO 326) is used. As there is a variation between individuals, the normal threshold is the hearing threshold separating the 50% best hearing from the 50% that hear less well. For an individual often that normal hearing threshold is taken as an indication, but for that person of course the individual hearing threshold is relevant. Hearing acuity may differ considerably between persons. Hearing generally deteriorates with age, but this is typically less so at lower frequencies when compared to higher frequencies.

1.3 Sound Levels in Practice

For a modern turbine, the maximum sound power level is in the range between 100 and 110 dBA. ‘Sound power’ is the total amount of sound radiated from a source. For a listener on the ground close to a turbine, the outdoor sound level will not be more than about 55 dBA. At residential locations this is often less and in most studies there are few people, if any, exposed to an average sound level of over 45 dBA. For a wind turbine, maximum sound levels are not much higher than average sound levels. For two turbine types in a temperate climate, it was shown that the sound level from these two types at high power is 1–3 dB above the sound level averaged over a long time [14].

Measurements on many types of modern wind turbines show that most sound energy is radiated at low and infrasound frequencies and less at higher frequencies (approximately 100–2000 Hz). However, because of the lower sensitivity of human hearing at low frequencies, audibility is greater at the higher frequencies. In the last decades wind turbines have become bigger and onshore wind turbines now can have several megawatts (MW) electric power. 2 MW turbines produce 9–10 dB more sound power when compared to 200 kW turbines [15,16]. Over time the amount of low-frequency sound (10–160 Hz) increases at nearly the same rate as the total sound level. Depending on what the reference situation is, this is somewhat less according to one author [15], somewhat more according to the other [16].

1.4 Aspects Other than Sound

Apart from sound, visual aspects, safety and vibrations related to wind turbines may also have an impact on the environment and the people living in it. Economic benefit, intrusion in privacy and acceptance of the wind turbines and other sources of disturbance are relevant to understand levels of annoyance. Also, personal and contextual aspects can determine the level of annoyance due to wind turbines.

2 Method

2.1 Data Sources and Search

This paper summarizes the present knowledge available about the association between wind turbine sound and health. It is based on several literature searches and reviews recently performed in the Netherlands [17,18] and updated with literature until February 2017, using the same method. Some papers from the most recent conference on Wind Turbine Noise (May 2017) have also been added to the overview in Sect. 4.

For this review a systematic literature search was performed at three moments in time (2000–2012; 2012–2015; and 2015–2017) using the same protocol. Observational as well as experimental studies described in the peer review literature in the period between 2009 and 2017 were included. Language was restricted to German, English, French and Dutch. The databases Scopus, Medline and Embase (note: only 2015–2017) were searched because these studies do not appear in the available reviews yet and they are of high value as they build on earlier evidence. The search strategy is described in Table 1.

Table 1 Key search terms and search profile

1	(Wind turbine* or wind farm* or windmill* or wind park* or wind power or wind energy).ti. (550)
2	Turbine noise*.tw. and wind/ (33)
3	(Power plants/ or energy-generating sources/ or electric power supplies/) and wind/ (187)
4	(Low frequency noise* or low frequency sound* or infrasound or infrasonic noise* or infrasonic sounds or infrasonic frequencies or low frequency threshold or (noise* adj4 low frequenc*)).ti. (500)
5	1 or 2 or 3 or 4 (1113)
6	(Wind turbine* or wind farm* or windmill* or wind park* or wind power or wind energy).ab. (803)
7	(Low frequency noise* or low frequency sound* or infrasound or infrasonic noise* or infrasonic sounds or infrasonic frequencies or low frequency threshold or (noise* adj4 low frequenc*)).ab. (1487)
8	Noise*.ti. (26930)
9	(6 or 7) and 8 (498)
10	(Impact or perception* or perceive* or health* or well-being or “quality of life” or syndrome*).ti. (1456358)
11	(Annoyance or annoying or annoyed or aversion or stress or complaints or distress or disturbance or adversely affected or concerns or worries or noise problems or noise perception or noise reception or noise sensitivity or (sensitivity adj3 noise) or sound pressure level* or sleep disturbance* or sleep quality or cognitive performance or emotions or anxiet* or attitude*).tw. (1260490)
12	(Social barrier* or social acceptance or popular opinion* or public resistance or (living adj4 vicinity) or (living adj4 proximity) or (residing adj4 vicinity) or (residing adj4 proximity) or living close or “living near” or residents or neighbors or neighbours).tw. (105942)
13	(Soundscape or landscape or visual annoyance or visual interference or visual perception or visual impact or visual preferences or visual assessment or visual effects or perceptual attribute*).tw. (41227)
14	(Effects adj4 population) or dose-response relationship* or exposure-response relationship* or dose response or exposure response or human response or health effects or health aspects or health outcome*).tw. (136924)
15	(Flicker or reflection).ti. (10980)
16	Environmental exposure/ or noise/ae or environmental pollution/ae (79725)
17	Loudness perception/ or psychoacoustics/ or auditory perception/ or auditory threshold/ or sensory thresholds/ or visual perception/ or motion perception/ (130572)
18	Sleep disorders/ or emotions/ or anger/ or anxienty/ or quality of life/ or epilepsy/ or attitude/ or affect/ or pressure/ or aesthetics/ or social environment/ or risk factors/ (1232239)
19	(Physiopathology or adverse effects).fs. (3235762)
Language: English or Dutch or French or German	
Search period: 2009–2017	
Duplicates removed	
Exclude animals/not humans	

We aimed to include low-frequency sound and infrasound in this review, but there are less publications and reviews specifically addressing this part of the spectrum. Also, the (alleged or studied) effects of infrasound and low-frequency sound are different from the effects of ‘normal’ sound. As a consequence, this topic is reviewed separately and is based on all relevant publications from the literature search (Fig. 1).

2.2 Inclusion Criteria

Only studies were included in which it was mentioned in the title, abstract or summary that the association was studied between the sound or noise of wind turbines and a reaction or effect concerning health or well-being. Also, studies addressing participation during the building process were accepted for review. This implied that the association between exposure to wind turbine (low-frequency) sound and annoyance, health, well-being or activity disturbance in the adult population was studied.

For a first selection the following criteria were used. Inclusion: papers address human health effects, perception, opinion, concern in relation to wind turbines. Exclusion: papers address non-human effects such as ecosystem effects, animals, papers solely about technical aspects of the wind turbines, papers regarding health effects of sound but not related to wind turbines. This resulted in total in 202 possi-

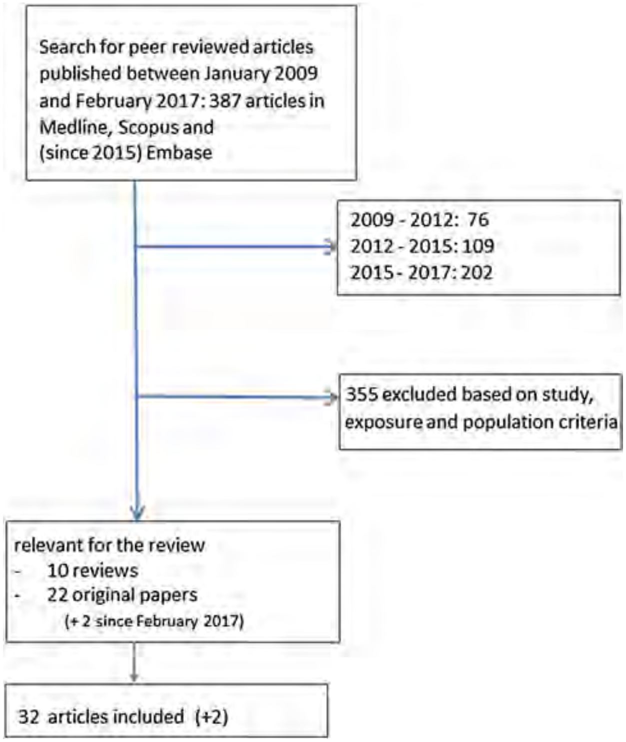

Fig. 1 Flowchart of selection process

bly relevant studies for the period between January 2015 and February 2017.

The papers for the period from January 2015 to February 2017 were grouped in seven categories: review, health effects, case studies, offshore, low-frequency sound/infrasound, visual aspects, social and not relevant. All reviews and health effects studies were included for full paper examination. All low-frequency sound/infrasound studies were examined for inclusion in the separate review. Offshore studies were a priori excluded; papers from the other categories were reconsidered after reading the abstracts.

Lastly, after full examination of the reviews and low-frequency sound/infrasound and health effect papers by the two authors, a final decision was made about inclusion in this review.

2.3 Procedure and Study Quality Assessment

This review is primarily based on results from epidemiological studies at population level and smaller-scale laboratory experiments.

The results have been divided into three sections. The difference in material between both periods (up to and since 2015) resulted in two sections: first we review the reviews (Sect. 3.1), and then we review original studies most of which are from the second period (3.2). The effects of infrasound and low-frequency sound are summarized in a third part (Sect. 4).

The main results are summarized per outcome. For the key studies, the study design and outcomes are discussed in more detail. For this review primarily scientific publications are used, from both peer-reviewed journals and conference proceedings. In some cases results are discussed which were described in non-scientific ('grey') literature. Also, some publications are mentioned that are often used in the debate (discourse) about the risks of living in the vicinity of wind turbines.

As usual, all material from the selected literature has been read and analysed, but not necessarily included as reference, e.g. because the study was less relevant than originally thought or in case of doubling with other references (e.g. a conference paper and an article from the same authors and study). A meta-analysis on (part of) the data was not considered in the time frame of this assignment.

3 Results

Annoyance and sleep disturbance are the most frequently studied health effects of wind turbine sound as is also the case for sound from other sources. After a short explanation of the health effects addressed in the literature, the overall conclusions from key reviews are summarized. Then the main findings for annoyance, sleep disturbance and other health effects are described in more detail, sometimes referring to the underlying publications. The influence of personal, situational and contextual factors on these effects is also included. Then in Sect. 3.2 the most recent original studies (2015–2017) are described separately in more detail while following the same structure.

Effects that are mentioned as specific effects of infrasound and/or low-frequency sound are treated in Sect. 4.

3.1 Evidence Until Early 2017: Reviews

People can experience annoyance or irritation, anger or disturbance from wind turbine sound, or when they feel that their environmental quality and quality of life deteriorates due to the siting of wind turbines near their homes.

The number of publications on wind turbine sound and its health effects has increased considerably in the past 10 years, including peer-reviewed articles, conference papers and policy documents (Table 2).

A remarkable number of nineteen reviews were published in the period between 2009 and 2017. These include systematic reviews as well as policy preparing reviews. Some reviews were dismissed after reading the full text, since they were highly anecdotal, no health impact was estimated, incomplete or only concerned occupational exposure, etc.

Table 2 Reviews (2009–2017) selected for this paper

First author year and reference	Studies included					Meta-analysis
	Number of studies evaluated	Number of participants	Time range	Exposure	Outcomes	
Knopper, (2011) [21]	15 studies	Na	2003 and 2011	Aspects of wind turbines broadly	Physiological and self-reported health effects, annoyance, stress, sleep disturbance, insomnia, anxiety	No
Harrison, (2015) [27]	Review of reviews	Na	2015	Low-frequency noise, levels < 100 dB SPL	Wind turbine syndrome. Vertigo, nausea and nystagmus, aural fullness, hyperacusis, and tinnitus	No
Ellenbogen (MPED), (2012) [22,23]	4 studies (peer-reviewed and 4 non-peer-reviewed	Na	2011	Aspects of wind turbines broadly: noise, shadow flicker, visual aspects, ice throw	Annoyance, sleep, health effects (self-reported, diagnosed)	No
Merlin, (2013) [19]	7 studies	2309 (79–754)	1981–2012	Infrasound/noise, electromagnetic interference, shadow flicker, blade glint	Adverse health effects (broad)	Yes
SHC, (2013) [20]	Na			Noise (including low-frequency noise, infrasound and vibrations) shadow flicker electromagnetic fields	Adverse health effects (broad)	No
Schmidt, (2014) [24]	36 studies	300–3000	2014	A-weighted sound exposure, < 30 dB $>$, infrasound, LFN, distance	Health, annoyance, tinnitus, vertigo, epilepsy, headache	No
MacCunney, (2014) [25]	20/14 studies	Na	2014	Distance, exposure, LFN infrasound	Sleep, cardiovascular, health, symptom, condition, disease	No
Knopper, (2014) [26]	60 studies	Na	2014	Noise, environmental change(s), wind, farm(s), infrasound, wind turbine(s), LFN, EMF, neighbourhood change	Annoyance, sleep disturbance, epilepsy, stress, health effect (wind turbine, syndrome	No, due to methodological, heterogeneity
Council of Canadian Academies, (2015) [28]	38 studies	Na	2009–2014	WT noise: a weighted SPL, infrasound, low-frequency sound and amplitude modulation	Annoyance sleep disturbance, tress, tension, health-related quality of life, vibroacoustic disease, cardiovascular system, endocrine system, immune system, musculoskeletal system, nervous system (general), nervous system (auditory), psychological health, respiratory system	No
Onakpoya, (2016) [1]	8 studies	2433	2000–2014	$>$ and $<$ 40 dB, distance	Annoyance and sleep disturbance	Yes

The remaining ten recent and leading reviews and policy documents (described in 11 manuscripts: [1,19–28] draw comparable conclusions about the health effects of wind turbine sound: in general, an association is found between annoyance and the level of wind turbine sound. Also, an association between sound level and sleep disturbance is considered plausible, even though a direct relation is uncertain because of the limited number of studies with sometimes contradictory results. Perceived stress is related to chronic annoyance or to the feeling that environmental quality and quality of life has diminished due to the placement of wind turbines, and there is sufficient evidence that stress can negatively affect people's health and well-being in people living in the vicinity of wind turbines [20].

Next to sound, vibration, shadow flicker, warning lights and other visual aspects have been examined in the reviews. There are no studies available yet about the long-term health effects. Such longitudinal studies (studies comparing the situation at different moments in time) might be useful to gain more insight in the causal pathways of the different factors. However, they can still only examine the strength of temporal associations across a range of relevant variables and to establish causal relations will remain problematic in this area.

Most recently, Onakpoya et al. [1] reanalysed the data from eight cross sectional studies, selected on strict quality requirements and including a total of 2433 participants. Effects considered were annoyance, sleep disturbance and quality of life. Evidence supports the earlier conclusion that there is an association between exposure to wind turbine sound and an increased frequency of annoyance and sleep problems, after adjustment for key variables as visual aspects, attitudes and background sound levels. The strength of evidence was the most convincing for annoyance, followed by sleep disturbance, when comparing participants at exposure levels below and above 40 dB. The findings are in line with Schmidt and Klokker [24] and Janssen et al. [29]. In contrast to these authors, Merlin et al. [19] consider annoyance a response to wind turbines and not a (health) effect as such.

Personal and contextual factors can influence annoyance. There is consensus in the literature that visual aspects, attitudes towards wind turbines in the landscape and towards the people responsible for wind farms, the process around planning and construction and economic interest can all in their own way affect levels of annoyance. However, actual evidence for this is still limited.

The next sections will describe the state of the art in more detail per health effect. Note that the description is limited to the effects of wind turbine sound in the 'normal' frequency range. Findings from studies, addressing suggested specific impacts of the low-frequency component and infrasound distinct from 'normal' sound are summarized separately in Sect. 4.

3.1.1 Noise Annoyance

In many countries the assessment of the sound of wind turbines is based on average, A-weighted sound levels (see Sect. 1.2). It is generally accepted that annoyance from wind turbines occurs at lower levels than is the case for traffic or industrial sound. Based on Dutch and Swedish data, an exposure–effect relation was derived between calculated sound exposure levels expressed in Lden (day–evening–night level) and the percentage highly annoyed, for indoor as well as outdoor exposures. Later research in Japan and Poland have confirmed these results and obtained similar results [30,31]. The relation between wind turbine sound and annoyance can be compared with those for road, rail and aircraft sound. This comparison is presented in Fig. 2 where the 'aircraft Europe' data are from the European HYENA study [32], the wind turbine data are from Janssen et al. [29], and the other data are from Miedema and Vos [33] for industrial sound and from Miedema and Oudshoorn [34] for air, road and rail transportation sound. The more recent HYENA study has shown that at a number of big European airports noise annoyance has increased when compared to the older data from Miedema and Oudshoorn [34]. Figure 2 shows that sound from wind turbines leads to a higher percentage of highly annoyed people when compared to other sound sources. The relation resembles that of air traffic sound, but near airports there are higher sound levels and a correspondingly higher percentage of highly annoyed. The relations for transport sound in Fig. 2 have been derived for large numbers of persons from many countries, but the actual percentage for a specific place or situation can be very different, for wind turbines as well as other sources.

Some think that it is too early to define exposure–effect relations for wind turbines [20,35]. According to them, the influence of context (like residential factors, trust in

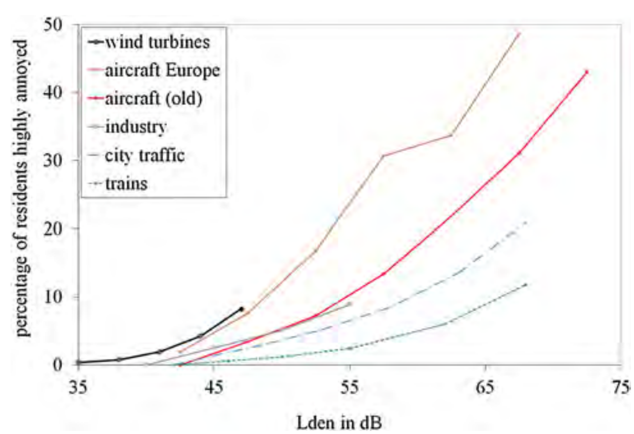

Fig. 2 Comparison of the percentage highly annoyed residents from sound of wind turbines, transportation and industry (approach adapted from Janssen et al. [51]); see text for explanation of legend

authorities and the planning process, situational factors) and personal factors (such as noise sensitivity and attitude) is so strong that the exposure–effect relation can only (or at best) give an indication of the percentage of highly annoyed at the local level [22,23].This is not unique to wind turbines, but is to some degree—also true for other sound sources and in part explains why in specific places or situations the actual percentage of annoyed persons can differ from the relations in Fig. 2. Michaud et al. [36] compared the results from five studies and found there was a 7.5 dB variation in wind turbine sound levels that led to the same percentage of annoyed persons.

What makes wind turbine sound so annoying?

In a Dutch survey [37] 75% of the respondents indicated that the terms ‘swishing/lashing’ gave the best description of wind turbine sound, irrespective of their being annoyed or not [37]. Laboratory studies have consistently shown that the periodic variation in the sound of wind turbines adds to the annoyance. In the study of Persson Waye and Öhrström [38] it was found that wind turbine sounds described as ‘swishing’, ‘lapping’ or ‘whistling’ were more annoying while the least annoying sounds were described as ‘grinding’ and ‘low frequency’ [38]. In the UK research was performed near three dwellings where people complained about wind turbine sound. Rather than the low-frequency component of the sound amplitude modulation or the rhythmic character was the most conspicuous aspect of the sound [39]. In a later UK study Large and Stigwood [40] concluded that amplitude modulation is an important aspect of the intrusiveness of wind turbine sound. More recently Yoon et al. [12] stated that there is a strong possibility that amplitude modulation is the main reason why wind turbine sound is easily detectable and relatively annoying.

Whether the type of environment affects the levels of annoyance is not yet clear. It can be assumed that people in rural areas are more likely to hear and see wind turbines than in more built-up urban areas with more buildings and a less open view. However, Dutch research showed that the percentage of highly annoyed people was equally high in rural and urban areas [37] although the correlation with the wind turbine sound level was less strong in the built-up area [41]. An important moderator was the existence of a busy road nearby, reducing the percentage annoyed by wind turbine sound annoyance in rural areas only. In a Swedish study it was found that residents in rural areas reported more annoyance in rural areas than in urban environments, possibly due to their expectation that the rural area would be quiet [42]. In a recent study Qu et al. [43] found that the level of annoyance from wind turbine sound in urban and suburban areas was less than reported in the Swedish, Dutch, Polish and Canadian studies in rural areas.

3.1.2 Sleep Disturbance

Good sleep is essential for physical and mental health. Sound is one of the factors that can disturb sleep or affect the quality of sleep. Several biological reactions to night time sound from different sources have been described in the literature: increased heart rate, waking up, difficulty in falling asleep and more body movements (motility) during sleep [4]. The night noise guidelines of the WHO are not specifically aimed at noise from wind turbines, but cover a range of (other) noise sources. It is conceivable that the relatively small but frequently occurring sound peaks just above the threshold for sleep disturbance due to the rhythmic character of wind turbine sound cause sleep disturbance [44]. A Dutch study found that wind turbine sound did not affect self-reported sleep onset latency but did negatively influence the ability to keep sleeping [37,41]. An increase in sound level above 45 dBA increased the probability of awakening. This was not the case for people who obtained economic benefit from the wind turbines, but this might also have been an age effect (co-owners of the turbines were younger). These findings of the study in the Netherlands are in line with the conclusions which the WHO drew from the review of scientific literature the relation between transport sound and sleep [4]. According to the WHO, sleep disturbance can occur at an average sound level at the facade at night (Lnight) of 40 dB and higher [4].

A direct association between wind turbine sound and sleep disturbance can only be determined when there is a measurable reaction to the sound. Such an immediate influence is only plausible when the sound level is sufficiently high and as yet has not been convincingly shown for wind turbine sound [23,45]. An indirect effect has been shown between self-reported sleep disturbance and annoyance from wind turbine sound, but not between sleep disturbance and the sound levels per se [41]. Research has shown that also for other sound sources there is a high correlation between self-reported sleep disturbance and annoyance from noise [46].

Several more recent studies show an association between quality of life and sleep disturbance and the distance of a dwelling to a wind turbine [47,48]. Differences in perceived quality of life were associated with annoyance and self-reported sleep disturbance in residents. These results are highly comparable with those found for air and road traffic, e.g. see [49].

3.1.3 Other Health Effects Due to Sound

In an Australian report [50] the number of people living in the vicinity of wind turbines with serious health complaints was estimated to be 10–15%. However, according to literature reviews on the health effects of wind turbines [1,19,20,23–25,28] there is no evidence for health effects caused by wind turbines in people living in the vicinity of wind turbines, other than annoyance and self-reported sleep disturbance and the latter is inconclusive. There was, however, a clear correlation between annoyance and self-reported sleep disturbance in one study [41]. Based on existing field studies, there is insufficient evidence that living near a wind turbine is the direct cause of health effects such as mental health problems, headaches, pain, stiffness or diseases such as diabetes, cardiovascular disease, tinnitus and hearing damage.

3.1.4 Influence of Situational and Personal Factors

Research in the past decade has shed some light on the question why some people are more disturbed by wind turbines than others. Next to physical aspects, personal and contextual aspects influence the level of annoyance. Often these aspects are referred to as non-acoustic factors, complementary to the acoustic factors (the 'decibels'). Because the term non-acoustic refers to a broad range of aspects, and as a result is very unspecific, we prefer the term personal and contextual factors [51]. They can be subdivided in the following categories (with some exemplary aspects in brackets):

- Situational factors (visual aspects frequency of sound events, meteorological circumstances, other sound sources, distance to amenities and attractiveness of the area).
- Demographic and socio-economic factors (age, gender, income, level of education);
- Personal factors (fear or worry in relation to source, noise sensitivity, economic benefit from the source);
- Social factors (expectation, attitudes towards producers or government, media coverage);

There is a lot of variation in the aspects studied and also the strength of the evidence varies strongly. Without pretending to be exhaustive, those aspects documented in the reviews on wind turbine sound up to 2015 are discussed in more detail below.

3.1.4.1 Visual Aspects

Modern wind turbines are visible from a considerable distance because they rise high and change the landscape. Due to the movement of their rotor blades, wind turbines are more salient in the landscape than objects that do not move. The rotating blades draw our attention and can cause variations in light intensity when the blades block or reflect sunlight. The visual and auditory aspects have been shown to be highly interrelated [19,36,52] and are therefore hard to unravel with respect to their effects. Annoyance from visual aspects may add to or even reinforce annoyance from noise (and vice versa). Noise and visual annoyance are strongly related as was also described above. It has been suggested [20] that people who see the wind turbines from their homes are more worried about the health effect of continuous exposure and as a consequence also report more annoyance [20].

3.1.4.2 Economic Aspects

Economic aspects can also affect annoyance from wind turbines. In a study of Pedersen et al. [52] in the Netherlands, some 14% of the respondents benefited from one or more wind turbines, in particular enterprising farmers who lived in general closer to the turbines and were exposed to higher sound levels than the remaining respondents. The percentage of annoyed persons in this group was low to very low, despite the higher exposure and the use of the same terms to describe the typical characteristics of wind turbine sound. In the study this group was described as 'healthy farmers': on average they were younger, more often male and had a higher level of education when compared to those not having economic benefits and reported less problems with health and sleep. However, it might not only be the benefit, but differences in attitude and perception as well as having more control over the placement of the turbines that might play a role [37].

3.1.4.3 Noise Sensitivity

Being noise sensitive refers to an internal state determined by physiological, psychological, attitudinal aspect, lifestyle and activities of a person that increases the reactivity to sound in general. Noise sensitivity has a strong genetic component (i.e. hereditary), but can also be a consequence of a disease (e.g. migraine) or trauma. Also, serious anxiety disorders can go together with an increased sensitivity to sound and possibly lead to a feeling of panic [53]. Only a few studies have addressed this issue in relation to wind turbine sound. An early example is the study of Shepherd et al. [47] in New Zealand, in which two groups were compared (a 'turbine group' versus a control group). Noise sensitivity was measured with a single question informing whether people considered themselves as noise sensitive. In the turbine group a strong association was found between noise sensitivity and annoyance and a weak association in the control group. This is indicative of an interaction effect of exposure and sensitivity on annoyance. This has also been documented for other sound sources [54]. According to a case report from Thorne [50], a relatively high proportion of residents near two wind farms in Australia were noise sensitive. Self-selection into a 'quiet area' by noise sensitive people can be a plausible explanation.

3.1.4.4 Social Aspects

For the social acceptance of wind turbine projects by a local community, the Belgian Superior Health Council [20] stated it is crucial how the community evaluates the consequences for their future quality of life. The communication and relation between the key parties (residents, municipality and project developer) are very important. Disturbance by wind turbines is a complex problem, in which the objective (physical) exposure and personal factors play a role, but also policy, psychology, communication and a feeling of justice.

When planning and participation are experienced as unjust or inadequate, public support will soon deteriorate, also among people who were originally neutral or in favour of the wind farm [55]. When residents feel they have been insufficiently heard, they feel powerless and experience a lack of control over their own environmental quality and quality of life. Worry or concern can be reduced by an open and honest procedure in which residents can contribute to the decisions in a positive way [56]. Already in the early phase of wind energy, research from Wolsink [57] and later from Breukers [58] showed that collaboration with emphasis on local topics was more successful than a policy aimed at as much wind energy as possible and a non-participatory approach.

Pedersen et al. [52] found that people who perceive the wind turbines as intruding and a threat to their privacy (motion, sound, visual) reported more annoyance. When people feel attached to their environment (‘place attachment’), the wind farm can form a threat to that location and can create resistance [59]. Also, a feeling of helplessness and procedural injustice can develop when people feel they have no real say in the planning process. Potentially, this plays a role especially in rural areas where people choose to live because of tranquillity; for them the wind park can form an important threat (visual and auditory). Based on renewable energy projects in the UK, Walker and Devine-Wright [60] concluded that the more people participated in project development, the higher was the public support for renewable energy in general.

3.2 Evidence Since 2015 Based on New Studies

In the period between January 2015 and 2017, 22 relevant publications were identified in peer-reviewed literature. These are 10 on field studies [36,61–69], 7 on experiments [12,70–75], 3 on a prospective cohort study [76–78], 1 panel study [79] and 1 qualitative analysis of interviews and discourse [80]. After the systematic literature search, two relevant papers from the most recent International Wind Turbine Noise Conference (Rotterdam 2017) were included [43,81].

Two major studies were (partly) reported in this period and not included in the reviews, one in Canada [16,61–65] and one in Japan [66,67]. The study from Health Canada [36,61–65] was performed with 1238 adult residents living at varying distances from wind turbines. A-weighted sound levels outdoors were calculated as well as C-weighted levels, and additional measurements were made at a number of locations. A strong point of the study is the high response rate of 79%. The results were presented in six publications, addressing effects on sleep, stress, quality of life, noise annoyance and health effects and a separate paper on the effect of shadow flicker on annoyance. Also, two papers were published describing the assessment of sound levels near wind turbines and near receivers [82,83]. The Japanese study by Kakeyama et al. [66,67] pertains a field study with structured face-to-face interviews at 34 study sites and 16 control sites. Wind turbine sound levels were estimated based on previous measurements at some sites and expressed in LAeq. Outcomes studied were sleep deprivation, sleep disturbance and physical and mental health symptoms (Table 3).

The next sections describe the state of the art in more detail per health effect as in 3.1. Note again that the description is limited to the effects of wind turbine sound in the ‘normal’ frequency range. Findings from studies addressing suggested specific impacts of the low-frequency component and infrasound distinct from ‘normal’ sound are summarized separately in Sect. 4.

3.2.1 Noise Annoyance

In one of his papers about the Health Canada study, Michaud et al. [61] describe the findings on annoyance, self-reported health and medication use. In line with earlier findings the study confirms that the percentage of highly annoyed increased significantly with increasing wind turbine sound levels. The effect was highest for annoyance with visual aspects of wind turbines, followed by blinking lights, shadow flicker, sound and vibrations.

An Iranian study of Abasssi et al. [68] included 53 workers divided in three job groups with repairing, security and administration tasks. The exposure level to wind turbine sound of employees at each job group was measured as an 8-h equivalent sound level as is usual in working conditions. Outcome measures included annoyance, sleep, psychological distress and health complaints. Noise sensitivity, age, job stress and shift work were accounted for. Annoyance was associated with measured sound levels but lower than found in residential studies. The other health outcomes did not show a significant association. It is not clear how this relates to residential conditions as the situations are quite different and different factors are involved.

In the period 2015–2017 several laboratory studies have addressed the effects of wind turbine sound and annoyance. In a listening test among 60 people, after a pilot in 12 people, an association was found by Schäffer et al. [70] between road traffic and wind turbine sound level or variations in sound level due to amplitude modulation and annoyance. Attitude towards wind turbines and noise sensitivity were important confounders, and the frequency of the amplitude modulation (higher for the wind turbine sound) seemed to play an important role.

The relative contribution of the typical characteristics of wind turbine sound, and particularly the rhythmic character or amplitude modulation (AM) was studied in several exper-

Table 3 Overview of the studies published after January 2015 and selected for this review

First author, year and reference	Studies included						
	Country	Number of participants	Design	Quality	Exposure	Outcomes	Effect
Michaud, (2016a) [61]	Canada	1238	Survey	objective and subjective measures	A waited SPL outdoors estimated + C-weighted	Annoyance, sleep disturbance, stress or psychological	The prevalence of self-reporting to be either 'very' or 'extremely' (i.e. highly) annoyed with several wind turbine, features increased significantly with increasing A-weighted levels
Michaud, (2016b) [62]	Canada	1238	Mixed	Objective and subjective measures	SPL 31–48 dB estimated + measurements on location	Sleep (actimeter), subjective sleep indicators	No effect on any of the sleep indicators
Michaud, (2016c) [63]	Canada	1238	Survey	Objective and subjective measures	A waited SPL outdoors estimated + C-weighted	Perceived stress scale (PSS) scores, hair cortisol concentrations, resting blood pressure and heart rate	The findings do not support an association between exposure to WTN up to 46 dBA and elevated self-reported and objectively defined measures of stress
Michaud, (2016d) [36]	Canada	1238	Survey	Objective and subjective measures	A waited SPL outdoors estimated + C-weighted	Noise annoyance, wind turbine perceptions, (including concern for physical safety) and a whole range of personal and situational aspects	Annoyance determined by other wind turbine-related, annoyances, personal benefit, noise sensitivity, physical safety concerns, property ownership and province: the community tolerance level (CTL) to WTN is 11 and 26 dB less than to other sources
Jalali, (2016a) [76]	Canada	T1-43, T2-31	Prospective cohort Before after	Objective and subjective measures		Annoyance, Qol subjective health, mental health	Significant effect on mental health and annoyance and symptoms. Interaction with negative attitude, worry about housing prize and visual complaints
Jalali, (2016b) [77]	Canada	16/2 nights	Prospective cohort Before after	Objective and subjective measures	Distance only	Sleep indicators with polysomnographic	No major change in sleep after placement of WT's
Jalali, (2016c) [78]	Canada		Prospective cohort Before after	Objective and subjective measures	Distance only	Pittsburg sleep quality, Epworth Sleepiness Scale and the Insomnia Severity Index	WT placement was associated with increased poor sleep quality, daytime sleepiness and rates of insomnia (expressed in th score on the PSQI and the ESS and the ISI. There was a strong association with negative attitude, worry about property values and WT visibility

Table 3 continued

First author, year and reference	Studies included						
	Country	Number of participants	Design	Quality	Exposure	Outcomes	Effect
Schäffer, (2016) [70]	Germany and Switzerland	60	Laboratory study	Test in j 12 pp of noise stimuli	WT < 55 versus traffic outdoor levels > 40 normal fluctuations due to weather conditions	Annoyance (short term) modifying effect of noise characteristics	Difference found but (much) smaller than Janssen and Michaud), AM next to noise level
Feder, (2015) [64]	Canada	1238	Field study	Objective and subjective measures	22–11 km and estimates based on ISO9613-1 and ISO9613-for each dwelling, dBA and dBC	WHO Qol annoyance, symptoms, sleep quality, perceived stress, life, style behaviours and prevalent chronic disease	No effects on Qol subscales below 46 dB
Chrichton, (2015) [71]	New Zealand	60	Laboratory study	Students/no control group	Up to 43 dB NZ standard for WT infra sound	Annoyance	Effect only in negative expectation group, interaction with NS
Blanes-Vidal, (2016) [69]	Denmark/USA	454	Cross sectional	Na	Distance to WT and number of turbines	Ideopathic symptoms	Effects on fatigue, difficulty concentrating, headache all disappeared after adjustment for noise exposure and odour from other sources
Ionannnidou, (2016) [72]	Denmark	19	Laboratory study	Na	Amplitude modulation elements 60 dBA 30 s M (approach van den Berg)	Annoyance	Check
Abassi, (2015) [68]	Iran	53	Field study	Na	8-h equivalent sound level (LAeq, 8 h) based on ISO 9612:2009	Annoyance, sleep psychological distress, health complaints	Annoyance associated with measured levels but lower than found in residential studies possibly due to economic benefits
Tonin, (2016) [74]	Australia	72	Laboratory study	More men	Infrasound exposure double blind (sham noise)	Annoyance, symptoms	Effects mediated by high/low expectancy
Hafke-Dys, (2016) [73]	Poland	21	Laboratory study	Control condition without modulation	Broadband and narrowband noise. With modulations typical, for WT (3, 6 and 9 dB) based on Renteghem	Annoyance	Interaction between noise type (broadband) and AM on annoyance. WT noise is perceived as less annoying when AM freq. is < 4 Hz
Yoon, (2016) [12]	Korea	24	Laboratory study	Control group	Amplitude modulation	Perceived loudness	Combined effect of noise levels and AM on noise perception

Table 3 continued

First author, year and reference	Studies included						
	Country	Number of participants	Design	Quality	Exposure	Outcomes	Effect
Botterill, (2016) [80]	Australia	Na	Interviews and discourse analysis	Na	Na	Topics mentioned most often in the discourse	Health and property values came forward as main topics
Kageyama, (2016) [66,67]	Japan	1079	Face-to-face structured interviews	Control sites! (16) versus 34 exp. sites	LAeq estimated based on some measurement sites, median 36–40 and 35 at control sites	Insomnia, physical and mental health, sensitivity to noise and visual annoyance	Odds ratio (OR) of insomnia was significantly higher when the noise exposure level exceeded 40 dB, self-reported sensitivity and visual annoyance independently associated with insomnia. OR of poor health only significant for, noise sensitivity and visual annoyance
Maffei, (2015) [75]	Italy	40	Listening, experiments	Exp versus control	Sound recordings of about 5 min were made at five distances	Noise recognition	Recognition is congruent with the increase of the distance and the decrease of the values of sound, equivalent levels and loudness
Krekel, (2016) [79]	France/Germany	30	Panel data	Na	(i) The exact geographical coordinates, (ii) the exact construction, dates and (iii) information on the size of the installation	Satisfaction with life	Geographical distribution of well-being merged with WT locations. Well-being data merged with
Voicescu, (2016) [65]	Canada	1238	Survey	Objective and subjective measures	Shadow flicker (SF) combined with noise estimates expressed in maximum minutes per day (SFm), modelled and based on distance	Annoyance, health complaints including dizziness	Annoyance associated with SF annoyance to other wind turbine-related features, concern for physical safety and noise sensitivity. Reported dizziness was also retained in the final model (all significant)

Table 3 continued

First author, year and reference	Studies included						
	Country	Number of participants	Design	Quality	Exposure	Outcomes	Effect
Yano, (2015) [30]	Japan	1079	Face-to-face interview	Control group (332) in areas with no wind turbines	Extra/interpolated from measured night time noise level ($L_{\mathrm{Aeq},n}$); distance for visual exposure	Noise annoyance, visual disturbance, perception of shadow flicker (SF)	$L_{\mathrm{Aeq},n}$ and distance significantly related to noise annoyance; distance more strongly associated with noise annoyance than level. Most annoyance reported at night-time. Visual annoyance not significantly related to distance, SF indoor and SF outdoor significantly related to distance. SF outdoor more prominent in mountainous area (compared to flat). Interaction between noise annoyance and visual annoyance/SF outdoor, not with visibility and SF indoors
Qu, (2017) [43]	England + Scotland	357	Survey in (sub)urban areas	No attribution to wind turbines in control group (96)	Calculated (maximum?) A-weighted wind turbine sound pressure level (SPL) on most exposed facade	Awareness of and annoyance with wind turbine noise, self-reported sleep disturbance, prevalence of specific health problems, general health, subjective well-being	SPL positively associated with noise annoyance. SPL not associated with sleep, but degree of noise annoyance significantly increased possibility of sleep disturbance. Visibility of wind turbine from both window and garden significantly increased odds of less deep sleep. In case group, annoyance with wind turbine noise significantly influenced prevalence of health problems: psychological problems significantly and positively associated with being annoyed by wind turbine noise, but not with SPL itself. Positive associations were found between SPL and adverse health problems, including nausea and dizziness. Dizziness and ear discomfort related to SPL in control group

iments. Ionannidou et al. [72] report on a study among 19 volunteers in which the effect of changes over time in the amplitude modulation of wind turbine sound on annoyance was investigated. The changes could either be the frequency of the modulation, the depth (or strength) of the modulation or a change in depth over time. The study confirms earlier results that AM leads to a higher annoyance rating. A higher modulation frequency (from 0.5 to 2 Hz) also resulted in a higher rating, but the effect was not significant. There was also a higher annoyance rating when the modulation depth increased intermittently, but again this was not significant. Because of the limited statistical power of these tests (because of the low number of participants and the limited time), it was recommended to investigate the variations in AM for a longer period and in a field setting.

A study from Hafke-Dys et al. [73] among 21 volunteers again concerned the effect of amplitude modulation on annoyance. In this study sounds with several modulation conditions were compared to a non-modulation condition. The test sounds used were (1) sound from moving cars, passing at a rate of 1–4 per second; (2) broadband sound with the same spectrum as wind turbines and (3) narrowband sound that could be modulated at 1, 2 and 4 Hz. All three types of sound had modulation depths typical for wind turbines at 3, 6 and 9 dB similar to Van Renterghem et al. [84], or zero (no modulation). Results showed that AM did increase annoyance in the case of broadband sound and passing cars, but not for the narrow band sound. The modulated sound was more annoying with increasing modulation frequency, in agreement with an expected highest sensitivity for modulated sounds at 4 Hz. Large, modern wind turbines modulate their sound at a frequency close to 1 Hz. The effect of AM on annoyance was less for the broadband sound than for passing cars. The main difference between these two sounds was the spectral content, with the broadband sound having more low-frequency sound than the passing cars. The authors conclude that this result supports the Japanese study [13] in which it was demonstrated ‘that low frequency components are not the most significant problem when it comes to the annoyance perception of wind turbine noise’.

Yoon et al. [12] studied the reaction to modulation of wind turbine sound in 12 people. Findings show again that there is an association between AM and level of annoyance. The authors conclude that there is a strong possibility that amplitude modulation is the main cause of two typical properties of wind turbine sound: that it is easily detectable and highly annoying at relatively lower sound levels than other noise sources. They add that this does not mean that these properties can be fully explained by the amplitude modulation.

Crichton and Petrie [71] studied 60 volunteers at exposure levels up to 43 dBA (the New Zealand standard limit) in combination with infrasound (9 Hz, 50 dB). In one group, the participants were shown a video about the health risk of wind turbine infrasound, and in the second group a video on health benefits was shown. An effect on annoyance was found only in the group expecting to be negatively affected, and in this group noise sensitivity increased the likelihood of being annoyed. In the group expecting a positive effect, there was far less annoyance and almost no influence from noise sensitivity.

In a later publication from the Japanese study, it was found that within 860 m from a wind farm 10% of the residents were annoyed by shadow flicker while within 780 m 10% of the residents were highly annoyed by wind turbine sound [81]. The authors concluded that a minimum distance (or ‘setback’) between residences and wind farms should be considered from an aural and visual point of view.

3.2.2 Sleep Disturbance

Michaud et al. [62] reported on sleep disturbance from a field study involving 742 of the 1238 respondents (as described under 3.2) wearing an actimeter, to measure relevant sleep indicators during 3–7 consecutive nights after the interviews. Outdoor wind turbine sound levels were calculated following international standards. Neither self-reported sleep quality, diagnosed sleep disorders nor objective measures such as sleep onset latency, awakenings and sleep efficiency showed an immediate association with exposure levels up to 46 dB after adjustment for relevant confounders such as age, caffeine use, body mass index (BMI) and health condition. This partly contrasts with earlier findings on subjective sleep measures [47]. No study addressed objective sleep measures in relation to wind turbines before. However, it should be mentioned that the method of actigraphy is limited as compared to more elaborate polysomnographic measures as were employed by Jalali et al. [76] and described below. In the Health Canada study having to close the window in order to guarantee an undisturbed sleep had by far the strongest influence on annoyance [61]. This could be a reason that no relation between wind turbine sound level and sleep disturbance was found: if persons disturbed at night by wind turbine sound would close their bedroom window, the result could be that they are less disturbed at night by the sound as such, although they could be annoyed because they had to close the window. The results do not directly support or negate this explanation. However, those closing their bedroom windows was eight times more likely to be annoyed. At higher wind turbine sound levels, people more often gave wind turbines as a reason for closing the bedroom window [61].

Kakeyama et al. [66,67] showed a significant association between sound levels above 40 dB and sleeping problems (insomnia). These findings are in contrast with those reported by Michaud et al. [62] who did not observe an immediate association between sound exposure levels up to 46 dBA and subjective and objective indicators for sleep. The earlier findings of Bakker [41] regarding subjective sleep indicators showed that sleep disturbance seemed to be related to sound level only when no others factors were included. When annoyance with wind turbine sound was included, then sleep disturbance was related to that annoyance and not anymore to sound level. Earlier, Pedersen and Persson [42] also concluded on an association between annoyance and sleep disturbance rather than a direct effect of sound level.

Jalali et al. [77] measured sleep disturbance in a group of 16 people for 2 consecutive nights using a polysomnographic method including a range of sleep and physiological parameters such as sleep onset, duration, movement during sleep, awakening, EEG activity. Sound measurements over the whole frequency range (0.5–20,000 Hz) were performed in the bedroom as well as outdoor, while accounting for weather conditions, wind speed and temperature. Factors that were taken into account were attitude, sensitivity, visibility, distance within 1000 m and windows open versus closed. Results showed no major changes in the sleep of participants who had new wind turbines in their community. There were no significant changes in the average indoor (31 dBA) and outdoor sound levels (40–45 dBA before, 38–42 dBA after) before and after the wind turbines became operational. None of the participants reported waking up to close their windows because of the outside noise. The lack of an effect might be explained by the limited measurements (two nights) or the low indoor sound levels that almost equalled the threshold value for sleep disturbance of 30 dBA.

In another paper Jalali et al. [78] report on the association between measured wind turbine sound levels and subjective sleep quality as measured with the Pittsburgh sleep quality index. Results show only an indirect association with attitude towards the wind turbines and concern about reduced housing values and the visibility of the turbine from the properties. The results confirm the strong psychological component and individual differences in sleep disturbance from wind turbine sound.

3.2.3 Other Health Effects Due to Sound

From the Canadian study Michaud et al. [61] concluded that, except for annoyance, the results do not support an association between exposure to wind turbine sound up to 46 dBA and the evaluated health-related end points, such as mental health problems, headaches, pain, stiffness, or diseases such as diabetes, cardiovascular disease, tinnitus and hearing damage. Michaud et al. [63] also studied the association between wind turbine sound level and objective stress indicators (cortisol, heart rate) and perceived stress (PPS index). These stress indicators were weakly associated with each other, but analysis showed no significant association between exposure to wind turbine sound (up to 46 dBA) and self-reported or objective measures of stress. The authors remarked that there was also no association between stress indicators and noise annoyance, which does not support the hypothesis that stress can be a consequence of chronic annoyance. The only wind turbine-related variable that had an influence on stress was high annoyance with the blinking lights on top of the wind turbines [63]. McCunney et al. [25] found an explanation for a lack of significant associations in the fact that sound levels from wind turbines do not reach levels which could cause such direct effects.

Results for quality of life (Qol) [64], measured using the WHO Qol index and including physical, environmental, social quality and satisfaction with health, showed no relation with sound levels (at levels up to 46 dB). This is in contrast with findings reported earlier by Shepherd et al. [47] and Nissenbaum et al. [48]. However, the results of these studies are hard to compare because the exposure levels are not the same and because different instruments were used to measure perceived quality of life

Tonin et al. [74] studied 72 volunteers in a laboratory setting for a double-blind test similar to that of Crichton et al. [71] but used infrasound at a higher level (91 dB). Before the listening test, participants were influenced to a high expectancy of negative effects from infrasound with a video of a wind farm affected couple, or a low expectancy of negative effects with a video of an academic explaining why infrasound is not a problem. Then normal wind turbine sound was presented via a headset to all participants with the inclusion of the infrasound or no infrasound for a period of 23 min. The infrasound had no statistically significant effect on the symptoms reported by participants, but the concern they had about the effect of infrasound had a statistically significant influence on the symptoms reported.

A survey in Denmark [69] among 454 citizens living in rural areas at different distances to wind turbine farms with a varying numbers of wind turbines studied the effect on non-specific symptoms. The study included idiopathic symptoms (i.e. not related to a specific disease) as effects and distance to the wind farm and the number of turbines as a measure of exposure. The originally positive association of distance with fatigue, headaches and concentration problems all disappeared after adjustment for exposure to sound and odour from other sources.

Jalali et al. [76] report on a prospective cohort (i.e. before–after) study with 43 participants who completed a questionnaire in spring 2014 and again a year later. Exposure to a wind farm was only measured in terms of distance. Residents who were annoyed by the sound or sight of turbines, or who had a negative attitude towards them or were concerned about property devaluation, after 1 year experienced lower mental health and life quality and reported more symptoms than residents who were not annoyed and had positive attitudes towards turbines. The response rate for this study was low (only 22%), and 12 people (of 43 that is approximately 25%) were not in the second round. Another weak point is the lack of a control group.

Against the background of the increasing number of wind farms in Germany, Krekel et al. [79] investigated the effect of the presence of wind turbines on residential well-being by combining household data from the German Socio-Economic Panel with a dataset on more than 20,000 wind turbines for the time period between 2000 and 2012. The key effect studied was life satisfaction. Results showed that the construction of one or more wind turbines in the neighbourhood of households had a significant negative effect on life satisfaction. This effect was limited in both distance and time.

More recent the first results were published of a new British study that was held near wind turbines in densely populated, suburban areas [43]. In this study part of the participants received a questionnaire that included explicit questions on the impacts of the local wind turbines on well-being, and the remaining part received a variant with no such questions. When including all participants, there was less annoyance from wind turbine sound in this study compared to what was found in earlier (Swedish, Dutch, Polish and Canadian) studies in rural areas. For the first group (with questions concerning local wind turbines), the sound levels were not significantly related to health problems and this group reported less health problems and better general health; this was opposite to the relationship found in the other, variant group.

3.2.4 Influence of Situational and Personal Factors

3.2.4.1 Visual Aspects

The paper of Voicescu et al. [65] on the Canadian data set (see Sect. 3.2) studied the effect of shadow flicker, expressed as the maximum duration in minutes per day, in combination with sound levels and distance, on annoyance and health complaints including dizziness. As shadow flicker exposure increased, the percentage of highly annoyed increased from 4% at short duration of shadow flicker ($<$ 10 min) to 21% at 30 min of shadow flicker. Variables associated with the percentage highly annoyed due to shadow flicker included concern for physical safety and noise sensitivity. Reported dizziness was also found to be significantly associated with shadow flicker.

3.2.4.2 Economic Aspects

In the study of Michaud et al. [16] personal (economic) benefit was associated with less annoyance, in a significant but modest way, when excluding factors that were likely to be a reaction (such as annoyance) to the wind turbine operation. The association between personal benefit from a wind turbine was also found in the Netherlands [85]. In the Japanese study from Kageyama et al. [66,67], this relationship was not found to be significant. However, it might not only be the benefit, but differences in attitude and perception as well as having more control over the placement of the turbines that might play a role [37].

3.2.4.3 Noise Sensitivity

Recent studies of Michaud et al. [36] and Kageyama et al. [66,67], both from 2016, confirm the independent role noise sensitivity has on reaction to wind turbines (see also Sect. 3.1.4.3). The influence of noise sensitivity on noise annoyance was reported earlier by many other researchers [42,59,86–88]. In all these studies, being highly noise sensitive was related to more annoyance. Similarly, the odds of reporting poor QoL and dissatisfaction with health were higher among those who were highly noise sensitive. However, after adjustment for current health status and work situation (unemployment) the influence of noise sensitivity became marginal. Fear and concern about the potential harm of wind turbines was an important predictor of annoyance as has been reported earlier for other noise sources [89–92].

In the Canadian study length of exposure seemed to be an important situational factor and led to up to 4 times higher levels of annoyance for people living more than 1 year in the vicinity of a wind turbine. This indicates sensitization to the sound rather than adaptation or habituation as is often assumed. The moderate effect of wind turbine sound level on annoyance and the range of (other) factors that predict the level of annoyance imply that efforts aimed at mitigating the community response to WTN will profit from considering other factors associated with annoyance. In the Japanese study [66,67] poor subjective health was not related to wind turbine sound levels, but again noise sensitivity and visual annoyance were significant predictors for the effects studied. Both noise sensitivity and visual annoyance seem, according to them, to be indicators of a certain vulnerability to environmental stimuli or changes in environmental factors.

Maffei et al. [75] studied 40 people subdivided in an experimental and control group (familiar for a long time with wind turbine sound versus not familiar). The study included a listening test to sound recorded at a wind farm of 34 wind turbines including background sound (wind in vegetation), or only background sound. Sound recordings of about 5-min duration were made at five distances (150, 200, 250, 300 and 1500 m) from the wind farm. For each distance 65 soundtracks were used. The aim was to detect wind turbine sound at varying distances. For both groups of participants, familiar and unfamiliar, there was no difference in recognition of wind turbine sound at distances of 300 m or less and detection was easiest at distances up to 250 m. At 1500 m those familiar with wind turbine sound could detect the sound better, but they also reported more often ‘false alarms’. Noise sensitivity was an important factor.

3.2.4.4 Social Aspects

According to Chapman et al. [93] and Crichton et al. [94], there is a strong psychogenic component in the relation between wind turbine sound and health complaints. This is not unique for wind turbine sound but has been documented for other sources as well, see e.g. [89,95,96]. In both studies [93,94] attention was given to expectations on the level of annoyance and the level of awareness (‘notice’) of the characteristics and prominent sounds of wind turbines [84]. The influence of these factors has been found in many studies regarding the effects of other sound sources [97]. In more recent years many researchers have investigated the social acceptance of wind projects in a number of countries by local communities and many stress the relevance of a fair planning process and local involvement [98–101]. The influence of injustice and fair planning process are confirmed in the most recent studies. Jalali [76] e.g. showed that concern about decreases in property values was associated with mental health problems.

Finally, Botterill and Cockfield [80] studied the discourse about wind turbines in submissions to public inquiries and in a small number of detailed interviews, and topics addressed in the discourse. Health and property values were found to be the most prominent topics discussed in the inquiries with regard to wind turbines in the submissions (and aesthetics/landscape arguments less often), but in the interviews these were never mentioned.

4 Health Effects of Low-Frequency Sound and Infrasound

In the non-scientific literature, which can be found on the internet, a range of health effects is attributed to the presence of wind turbines. Infrasound is described as an important cause of these effects, also when the infrasound levels must be very low or are unknown. In this section the question is whether infrasound or low-frequency sound deserves special consideration with respect to the effects of wind turbine sound. There is some discrepancy when comparing conclusions from the majority of scientific publications to conclusions in popular publications. Also, some scientific publications suggest possible impacts that are not generally supported. The findings regarding low-frequency sound and infrasound are not easy to interpret. It may be confusing that the frequency of the rhythmic changes in sound due to amplitude modulation is the same as the frequency of an infrasound component. Also, some authors conclude that low-frequency sound and infrasound play a role in the reactions to wind turbine sound that is different from the effects of ‘normal’ sound [16,102] which is contested by many others. In general, however, there is little definite evidence on specific health effects of low-frequency sound when compared to health effects from ‘normal’ sound [103].

First, we will consider the audibility of infrasound and low-frequency sound and then possible health effects not involving audibility. Because we are, in the case of low-frequency sound and infrasound, dealing with other health effects, the paragraphs are structured different than was the case in the previous section.

4.1 Audibility of Infrasound and Low-Frequency Sound

Audible low-frequency sound is all around us, e.g. in road and air traffic. Audible infrasound is less ubiquitous, but can be heard from big machines and storms. In most publications on wind turbine sound, there is agreement that infrasound and low-frequency sound are both present in wind turbine sound. Generally, it is acknowledged that wind turbine infrasound is inaudible as infrasound levels are low with respect to human sensitivity [16,19,25,104,105].

Even close to a wind turbine, most authors argue that infrasound is not a problem with modern wind turbines. This can be shown from measurement results at 10 and 20 Hz. At the (infrasound) frequency of 10 Hz the A-weighted sound power level is typically 60 dB lower than the total sound level in dBA [15]. At a receiver with a total sound level of 45 dBA this means that the 10 Hz sound level is about minus 15 dBA or, in physical terms (not A-weighted), 55 dB. This is far below the hearing threshold at that frequency, which for normal-hearing persons is about 95 dB. A sound of 55 dB at 10 Hz would also be inaudible for the few persons that have been reported with a much lower hearing threshold (close to 80 dB). At 20 Hz, the upper frequency limit of infrasound, the result, again at a receiver total sound level of 45 dBA, would be a physical level of wind turbine sound of 50–55 dB which is much lower than the normal hearing threshold at that frequency of 80 dB [106].

As a part of a Japanese study on wind turbine low-frequency sound, persons in a laboratory were subjected to wind turbine sound where very low frequencies were filtered out over different frequency ranges [13]. When infrasound frequencies were filtered out, the study persons did not note different sensations. Above about 30 Hz they began to notice a difference between the filtered and original sound.

Leventhall [107] states that the human body produces infrasound internally (through blood flow, heartbeat and breathing, etc.) and this would mask infrasound from outside sources when this sound is below the hearing threshold.

In contrast to infrasound, there is general agreement that low-frequency sound is part of the audible sound of wind turbines and therefore contributes to the effects caused by wind turbine sound. The loudest part of the sound as radiated by a turbine is in the mid-frequency range (250–1600 Hz) [15,16]. This shifts to lower frequencies when the sound travels through the atmosphere and enters a building because absorption by the atmosphere and a building facade reduces low frequencies less than higher frequencies. However, studying the effects of the low frequencies separately from the higher frequencies is not easy as both frequency ranges automatically go together: wind turbines all have very much the same sound composition. In a Canadian study on wind turbines, the sound levels at the facades of dwellings were calculated as both A- and C-weighted sound levels, but this proved not to be an advantage as the two were so closely linked that there was no added value in using both [82]. A limit in A-weighted decibels (where the A-weighting mimics human hearing at moderate sound levels) thus automatically limits the low-frequency part of the sound [105].

Bolin et al. [108] calculated and compared wind turbine and road traffic sound over a broad frequency range (0–2000 Hz) at sound levels considered acceptable in planning guidelines (40 dB L_{Aeq} for wind turbine sound and 55 dB L_{Aeq} for road traffic sound). Compared to road traffic sound, wind turbine sound had lower levels at low frequencies. Thus, at levels often found in urban residential areas, low-frequency sound from wind turbines is less loud than from road traffic sound. Recent measurements in dwellings and residential areas show that similar levels of infrasound occur, when comparing wind turbine sound with sound from traffic or household appliances [109].

4.2 Effect of Lower Frequencies

McCunney et al. [25] mention that both infrasound and low-frequency sound have been suggested to pose possibly unique health hazards associated with wind turbine operations. From their review of the literature, including results from field measurements of wind turbine-related sound and experimental studies in which people have been purposely exposed to infrasound, they conclude that there is no scientific evidence to support the hypothesis that wind turbine infrasound and low-frequency sound has effects that other sources of infra/low-frequency sound do not have.

4.3 Subaudible Effects

Several authors have linked infrasound and low-frequency sound from wind turbines to health effects experienced by residents, assuming that infrasound can have physiological effects at levels below the (normal) hearing threshold [110–112]. This was supported by Salt and Kaltenbach [113] who argued that normal hearing is the result of inner hair cells in the inner ear producing electric signals to the brain in response to sound received by the ear. However, infrasound and low-frequency sound (up to 100 Hz) can also lead to signals from the outer hair cells (OHC) and the threshold for this is lower than for the inner hair cells. This means that inaudible levels of infrasound and low-frequency sound can still evoke a response [113]. The OHC threshold is 60 dB at 10 Hz and 48 dB at 20 Hz. Comparing this to actual sound levels (see Sect. 4.1) shows that infrasound levels from wind turbines could just exceed this OHC threshold when their total outdoor sound level is 45 dBA. It is unlikely that the OHC threshold can be exceeded indoors, where levels are lower, except at a high sound level that may occur very close to a wind turbine. Salt and Kaltenbach [113] conclude from this that it is ‘scientifically possible’ that infrasound from wind turbines thus could affect people living nearby. However, it is not clear to what reactions these signals would lead or if they could be detrimental when just exceeding the OHC threshold. If such inaudible sound could have effects, it is not clear why this has never been observed with everyday sources (other than wind turbines) that produce infrasound and low-frequency sound such as strong winds, road and air traffic, or with physiological sounds from heartbeat, blood flow, etc.

Farboud et al. [114] conclude that physiological effects from infrasound and low-frequency sound need to be better understood; it is impossible to state conclusively that exposure to wind turbine sound does not cause the symptoms described by authors such as Salt and Hullar or Pierpont.

Leventhall [107] argues that infrasound at low level is not known to have an effect. Normal pressure variations inside the body (from heart beat and breathing) cause infrasound levels in the inner ear that are greater than the levels from wind turbines. From exposure to high levels of infrasound, such as in rocket launches and associated laboratory studies or from natural infrasound sources, there is no evidence that infrasound at levels of 120–130 dB causes physical damage to humans, although the exposure may be unpleasant [107].

Stead et al. [115] come to a similar conclusion when considering the regular pressure changes at the ear when a person is walking at a steady pace. The up and down movement of the head implies a slight change in atmospheric pressure that corresponds to pressure ‘sound’ levels in the order of 75 dB. The pressure changes in the rhythm of the walking frequency are similar in frequency (close to 1 Hz), and level to the pressure changes from infrasound at rotation frequencies measured at houses near wind farms.

4.4 Vestibular Effects

According to Pierpont the (infra)sound of wind turbines can cause visceral vibratory vestibular disease (VVVD), affecting the vestibular system from which we derive our sense of balance. She characterized this new disease with the following symptoms: ‘a feeling of internal pulsation, quivering or jitteriness, and it is accompanied by nervousness, anxiety, fear, a compulsion to flee or check the environment for safety, nausea, chest tightness, and tachycardia’ [111], stating that infrasound and low-frequency sound were causing this 'wind turbine syndrome'. Pierpont's research was based on complaints from 38 people from 10 families who lived within 300–1500 m from one or more turbines in the USA or Great Britain, Italy, Ireland and Canada. In several publications (e.g. [22,25]), it was pointed out that Pierpont's selection procedure was to find people who suffer the most, and it was not made clear that it was indeed the presence of the wind turbine(s) that caused these symptoms. Although the complaints may be genuine, it is possible that very sensitive people were selected and/or media coverage had led to physical symptoms attributed to environmental exposures as has been demonstrated for wind turbines [93] and other environmental exposures [116]. Van den Berg [44] noted that the symptoms of VVVD are mentioned in the Diagnostic and Statistical Manual of Mental Disorders (DSM) as stress symptoms in three disorders: an adjustment disorder, a panic disorder and a generalized anxiety disorder. The wind turbine syndrome may thus not be a new phenomenon, but an expression of stress that people have and which could have a relation to their concern or annoyance with respect to a (planned) wind farm.

In his examination of the wind turbine syndrome, Harrison [27] argued that at a level of 40–50 dBA no component of wind turbine sound approaches levels high enough to activate the vestibular system. The threshold for this is about 110 dB for people without hearing ailments. In people with a hearing ailment, particularly the 'superior (semicircular) canal dehiscence syndrome' (SCDS), this threshold is lower and can be 85 dB. Such levels are only reported very close to wind turbines. Reports show that 1–5% of the adult population may have (possibly undiagnosed) SCDS.

Schomer et al. [117] studied residents of three homes where residents generally did not hear the wind turbines in their area, but they did report symptoms comparable to motion sickness. Schomer et al. suggest that this could result from sound affecting the vestibular sensory cells and in their opinion wind turbine infrasound could generate a pressure that they compare with an acceleration exceeding the U.S. Navy's criteria for motion sickness. This has been investigated by Nussbaum and Reinis much earlier [118]. They exposed 60 subjects to a tone of 8 Hz and 130 dB with high distortion (high-level harmonics at multiples of 8 Hz) or low distortion (harmonics at lower level). Dizziness and nausea were primarily associated with the low distortion exposure, i.e. a relatively high infrasound content. In contrast, headache and fatigue were primarily associated with the high distortion exposure, with a relatively low infrasound content. Nussbaum and Reinis [118] hypothesized that the effects of the purer infrasound could be explained as acoustically induced motion sickness. However, this was concluded from exposure levels (130 dB) much higher than wind turbines can cause.

4.5 Vibroacoustic Disease

According to Alves-Pereira and Castelo Branco [112], the infrasound and low-frequency sound of a wind turbine can cause vibroacoustic disease (VAD), an affliction identified by a thickening of the mitral valve (one of the valves in the heart) and the pericardium (a sac containing the heart). The most important data regarding VAD are derived from a study among aircraft technicians who were professionally exposed to high levels of low-frequency sound [119]. VAD is controversial as a syndrome or disease. Results of animal studies have only been obtained in studies using low-frequency sound levels which are found in industrial settings. No studies are known that use a properly selected control group. And finally, the way the disease was diagnosed has been criticized because of a lack of precision [120]

After investigating a family with two wind turbines at 322 and 642 m from their dwelling, Alves-Pereira and Castelo Branco [112] concluded that VAD occurred and was caused by low-frequency sound. The measured sound levels were substantially lower (20 dB or more) than levels at which VAD was thought to occur by Marciniak et al. [119] and the levels were below the normal hearing threshold for a considerable range of frequencies in this range. In their review of evidence on VAD Chapman et al. [93] concluded that in the scientific community VAD was only supported by the group who coined the term and there is no evidence that vibroacoustic disease is associated with or caused by wind turbines.

4.6 Effect of Vibrations

Vibrations from wind turbines can lead to ground vibrations and these can be measured with sensitive vibrations sensors. In several studies vibrations have been measured at large distances, but this was because these vibrations could affect the performance of seismic stations that detect nuclear tests. These vibrations are too weak to be detected or to affect humans, even for people living close to wind turbines [98].

In measurements at three dwellings, Cooper et al. [104] found surges in ground vibration near wind turbines that were associated with wind gusts, outside as well as inside one of the three houses. Vibration levels were weak (less than from people moving around), but measurable. According to Cooper, two residents were clearly more sensitive than the other four; the sensations experienced by the residents seemed to be more related to a reaction to the operation of the wind turbines than to the sound or vibration of the wind turbines. This echoes earlier findings from Kelley [121] who investigated complaints, from two residences, that were thought to be associated with strong low-frequency sound pulses from the experimental downwind MOD-1 wind turbine. The low-frequency sound pulses were generated when a turbine blade passed the wind wake behind the mast. The residents perceived 'audible and other sensations, including vibration and sensed pressure changes'. Although the wind turbine sound at frequencies below about 30 Hz was below the normal hearing threshold, this sound was believed to be causing the annoyance complaints. The sound levels were within a range of sound levels and frequencies cited in a report from Stephens et al. [122] for situations where (sub-audible) industrial sound within this range was believed to be the source of the complaints. This could be explained by the response of a building to the sound outside: the distribution of sound pressure in the building can be the result of structure-borne sound, standing waves and resonances due to the configuration of a room, closet and/or hallway. The rhythmic character of wind turbine sound could have an added effect because of the periodic pressure pulses; if these coincide with a structural resonance of the building the indoor level can be higher than expected from just reduction by the facade. These structural vibrations can lead to sound at higher frequencies which are audible. Several authors have pointed out that the rhythmic character itself (technically, amplitude modulation) is more relevant to human perception than low-frequency sound or infrasound (see *What makes wind turbine sound so annoying?* in Sect. 3.1.1). However, the appreciation of the sound may depend on a combination of the frequency and strength of the modulation and the balance of low- and higher-frequency components [123].

5 Discussion and Conclusions

5.1 Primary Findings

This review summarizes the findings of ten previous reviews on the effect of wind turbines on health and the role of personal, situational and physical factors other than sound. In addition, the results from 22 papers that were published later (after early 2015) were reviewed. The results will be presented here with an indication of a possible change over time when comparing evidence before and since 2015.

Results confirm the earlier evidence that living in areas with wind turbines is associated with an increased percentage of highly annoyed residents. Earlier findings of a possible association with perceived and measured sleep disturbances are not confirmed in the latest studies, nor does recent evidence support the notion of a possibly decreased quality of life in relation to exposure to wind turbine sound. Also, the findings of recent studies do not support a relation between subjective and objective stress indicators and exposure to wind turbine sound. Earlier findings on personal, situational and contextual factors (such as visual aspects, attitude, benefits, perceived injustice and fair planning process) are confirmed in the most recent studies. Available scientific research does not provide a definite answer about the question whether wind turbine sound can cause health effects which are different from those of other sound sources. However, wind turbines do stand out because of their rhythmic character, both visually and aurally. Several new laboratory studies have in particular addressed the role of amplitude modulation (AM). Results are inconclusive regarding the effect of amplitude modulation on annoyance. A common conclusion seems to be that AM appears to aggravate existing annoyance, but does not lead to annoyance in persons who benefit from or have a positive attitude towards wind turbines. Recent reviews of McCunney et al. [25] and Harrisson [27] conclude that there is no scientific evidence to support the hypothesis that wind turbine infrasound and low-frequency sound have effects that other sources do not have. In general, evidence on specific health effects of low-frequency sound is limited. As the CCA [28] worded it: knowledge gaps remain with regard to the influence of specific sound characteristics, such as amplitude modulation, low-frequency content or visual aspects of wind turbines, which are difficult to study in isolation.

The recent studies largely support earlier scientific findings but have improved the state of the art with thorough research and adding objective measures to self-reported effects. Exposure characterization has been improved considerably by including local sound measurements in field studies, and the recent AM studies have improved the knowledge base considerably.

5.2 Discussion

5.2.1 Physical, Social and Personal Factors Add

There are many models or schemes that show how people react to sound. However, much of the public debate about wind turbines and sound is at the planning stage when wind turbines are not yet present. Michaud et al. [63] proposed a model that incorporates the influence of (media) information and expectations as well as actual wind turbine sound exposure. In Fig. 3 we present a simplified model based on the one from Michaud et al. [63]. It shows that plans for wind turbines or actual wind turbines can lead to disturbances and concern, but a number of factors can influence the effect of the (planned) turbines (see 'Michaud model' for these factors). Personal factors include attitude, expectations, noise sensitivity. Situational factors include other possible impacts such as visibility or shadow flicker, other sound sources, type of area. Contextual factors include participation, the decision-making process, the siting procedure, procedural justice.

The model illustrates that next to wind turbine sound itself, several other features are relevant for residents living in the vicinity of wind turbines. These include physical and personal aspects, and the particular circumstances around decision-making and siting of a wind farm as well as commu-

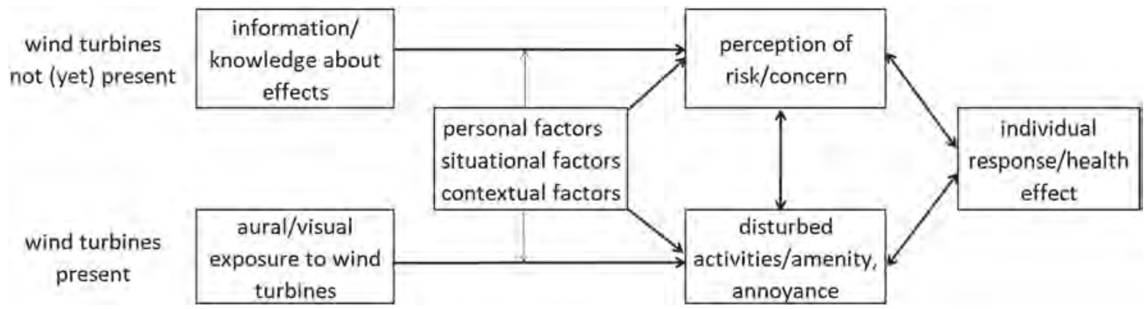

Fig. 3 A graphic summary model for the relationship between exposure to wind turbines and individual response (after Michaud et al. [63])

nication and the relation between different people involved in the process. There is consensus that visual aspects play a key role in reactions to wind turbines and this includes the (mis-)match with the landscape, shadow casting and blinking lights. Shadow casting from wind turbines is described as annoying for people and also the movement of the rotor blades themselves can be experienced as disturbing. Light reflection/flicker from the blades and vibrations play a minor role in modern turbines as far as the effect on residents is concerned. It has been shown that people who benefit from and/or have a positive attitude towards wind turbines in their environment in general report less annoyance. People who perceive wind turbines as intruding into their privacy and detrimental to the quality of their living environment in general report more annoyance. Perceived (procedural) injustice has been found to be related with the feeling of intrusion and lack of control/helplessness. Most studies confirm the role of noise sensitivity in the reaction to wind turbines, independent of the sound level or sound characteristics. Attitude and media coverage are just a few elements of the complex process of policy and decision-making for siting wind turbines. Most recent studies conclude that social acceptance of wind projects is highly dependent on a fair planning process and local involvement. The latest evidence seems to confirm the role of these factors described in earlier reviews and studies.

5.2.2 Evidence on Adverse Effects of Wind Turbine Sound

Noise annoyance is the main health effect associated with the exposure to sound from an operational wind turbine. At equal sound levels, sound from wind turbines is experienced as more annoying than that of traffic sources [19,29]. From epidemiological and laboratory studies, the typical character of wind turbine sound comes forward as one of the key issues. Particularly, the rhythmic character of the sound (technically, amplitude modulation or AM), described as a swishing or wooshing sound, is experienced as annoying. Residential wind turbine sound levels themselves are modest when compared to those from other sources such as road or industrial sound. However, recent laboratory studies [12,71,72] are inconclusive regarding the effect of amplitude modulation on annoyance. One conclusion is that ‘there is a strong possibility that amplitude modulation is the main cause of the properties of wind turbine noise’, in which properties refer to sounds that are easily detectable and highly annoying at relatively low sound levels [12]. Another dismisses amplitude modulation as a negative factor per se because it is highly related to attitude [72]. A common factor is that AM appears to aggravate existing annoyance, but does not lead to annoyance for persons positive about or benefiting from wind turbines. The general exposure–effect relation for annoyance from wind turbine sound includes all aspects that influence annoyance and thus averages over all local situations and non-acoustic factors. The relation can therefore only form an indication of the annoyance levels to be expected in a local situation.

New evidence regarding the effect of night time wind turbine sound exposure on sleep suggests no direct effect, but remains inconclusive. The current results do not allow a definite conclusion regarding both subjective and objective sleep indicators [62]. However, studies do find a relationship between self-reported sleep disturbance and annoyance from wind turbines [41] and between self-reported sleep disturbance and perceived quality of life [47,48].

For other health effects, there is insufficient evidence for a direct relation with wind turbine sound levels.

Based on noise research in general, we can conclude that chronic annoyance from wind turbines and the feeling that the quality of the living environment has deteriorated or will do so in the future, and can have a negative impact on well-being and health in people living in the vicinity of wind turbines. This is similar to the effect of other stressors [19]. The moderate effect of the level of wind turbine sound on annoyance and considering the range of factors that influence the levels of annoyance implies that reducing the impact of wind turbine sound will profit from considering other factors associated with annoyance. The influence of these factors is not necessarily unique for wind turbines. The fact that residents can respond very differently to a sound shows that annoyance from a sound is not inextricably bound up with that sound.

5.2.3 Evidence on Adverse Effects of Low-Frequency Sound and Infrasound

There is substantial knowledge about the physical aspects of low-frequency sound. Low-frequency sound can be heard daily from road and air traffic and many other sources. Less is known about infrasound and certainly the perception of infrasound. Infrasound can sometimes be heard, e.g. from big machines and storms, but is not as common as low-frequency or 'normal' sound. However, with sensitive equipment infrasound, as well as vibrations, can be measured at large distances. Infrasound and low-frequency sound are present in wind turbine sound. Low-frequency sound is included in most studies as part of the normal sound range. In contrast, infrasound is in most studies considered as inaudible as the level of infrasound is low with respect to human sensitivity. Studies of the perception of wind turbine infrasound support this. Infrasound and low-frequency sound from wind turbines have been suggested to pose unique health hazards. There is little scientific evidence to support this. The levels of infrasound involved are comparable to the level of internal body sounds and pressure variations at the ear while walking. Infrasound from wind turbines is not loud enough to influence the sense of balance (i.e. activate the vestibular system), except perhaps for persons with a specific hearing condition (SCDS). Effects such as dizziness and nausea, or motion sickness, could be an effect of infrasound, but are expected at much higher levels than wind turbines produce in residential situations. Vibroacoustic disease and the wind turbine syndrome are controversial and scientifically not supported. At the present levels of wind turbine sound, the alleged occurrence of vibroacoustic disease (VAD) or the disease (VVVD) causing the wind turbine syndrome (WTS) is unproven and unlikely. However, the symptoms associated with WTS are symptoms found in relation to stress.

The rhythmic character of wind turbine sound is caused by a succession of sound pulses produced by the blade rotations. From early research it was concluded that this may lead to structural vibrations of a house and wind turbines thus may be perceived indirectly inside a house and hence lead to annoyance. This possibility needs further investigation.

5.3 Strengths and Limitations

The strengths of this review are the use of a robust search strategy to identify relevant studies, its broad approach in terms of both the range of outcomes and noise characteristics considered and the special consideration of the role of low-frequency sound and infrasound. We also tried to make the available knowledge accessible for a broader audience by avoiding technical terms as much as possible. We added to earlier reviews by reviewing the latest studies which are of high quality and have shown how the state of knowledge developed over time. However, we recognize limitations as well. Although the literature search was performed systematically, the review is primarily a narrative one and in this sense will repeat in a less rigid manner the conclusions of previous reviews. Although the studies were systematically selected and structured, in our wording and interpretation we follow a 'story line' inherent to a narrative review. The text reflects our view, based on an extensive amount of knowledge of (reactions to) wind turbine sound and environmental sound in general.

5.4 Methodological Considerations and Implications for Future Research

Again, or we might say still, we can conclude that the earlier identified lack of methodological and statistical strength of wind turbine studies by CCA [28] still holds. With a few exceptions in general, the sample size of most studies is limited, and with regard to both the exposure and outcomes, there is room for improvement.

5.5 Final Conclusion

Systematic reviews published since 2009 including some recent and high quality ones, and new evidence not yet reviewed suggest that exposure to wind turbine sound is associated with higher odds for annoyance. The proximity of a wind turbine or wind farm has not conclusively been proven to negatively affect stress responses, quality of life, sleep quality (subjective and objective) nor other health complaints. A reason for this may be that individual traits and attitudes, visual aspects as well as the process of wind farm planning and decision-making are highly likely to influence the response to sound from wind turbines. Larger-scale studies at locations with varying circumstances and with a before after component (prospective cohort) are recommended for the future. Ideally measured sound levels over the whole frequency range and routinely collected registry health data should be used in conjunction with more subjective data.

Acknowledgements The basis for this text is a report that was written at the request of the Noise and NIR Division of the Swiss Federal Office for the Environment (Bundesamt für Umwelt). We thank Professor Geoff Leventhall and Professor Kerstin Persson Waye as well as Dr. Mark Brink for their useful comments to earlier versions of this manuscript.

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EXHIBIT
18

PLOS ONE

RESEARCH ARTICLE

Health Effects Related to Wind Turbine Noise Exposure: A Systematic Review

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Abstract

Background: Wind turbine noise exposure and suspected health-related effects thereof have attracted substantial attention. Various symptoms such as sleep-related problems, headache, tinnitus and vertigo have been described by subjects suspected of having been exposed to wind turbine noise.

Objective: This review was conducted systematically with the purpose of identifying any reported associations between wind turbine noise exposure and suspected health-related effects.

Data Sources: A search of the scientific literature concerning the health-related effects of wind turbine noise was conducted on PubMed, Web of Science, Google Scholar and various other Internet sources.

Study Eligibility Criteria: All studies investigating suspected health-related outcomes associated with wind turbine noise exposure were included.

Results: Wind turbines emit noise, including low-frequency noise, which decreases incrementally with increases in distance from the wind turbines. Likewise, evidence of a dose-response relationship between wind turbine noise linked to noise annoyance, sleep disturbance and possibly even psychological distress was present in the literature. Currently, there is no further existing statistically-significant evidence indicating any association between wind turbine noise exposure and tinnitus, hearing loss, vertigo or headache.

Limitations: Selection bias and information bias of differing magnitudes were found to be present in all current studies investigating wind turbine noise exposure and adverse health effects. Only articles published in English, German or Scandinavian languages were reviewed.

Conclusions: Exposure to wind turbines does seem to increase the risk of annoyance and self-reported sleep disturbance in a dose-response relationship.

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Citation: Schmidt JH, Klokker M (2014) Health Effects Related to Wind Turbine Noise Exposure: A Systematic Review. PLoS ONE 9(12): e114183. doi:10.1371/journal.pone.0114183

Editor: Shilu Tong, Queensland University of Technology, Australia

Received: April 24, 2014

Accepted: November 5, 2014

Published: December 4, 2014

Data Availability: The authors confirm that all data underlying the findings are fully available without restriction. All relevant data are within the paper.

Funding: The authors have no support or funding to report.

Competing Interests: The authors have declared that no competing interests exist.

There appears, though, to be a tolerable level of around L_{Aeq} of 35 dB. Of the many other claimed health effects of wind turbine noise exposure reported in the literature, however, no conclusive evidence could be found. Future studies should focus on investigations aimed at objectively demonstrating whether or not measureable health-related outcomes can be proven to fluctuate depending on exposure to wind turbines.

Introduction

In recent years suspected health-related effects of exposure to wind turbine noise have attracted much public attention. Whether or not this exposure can result in an array of described symptoms and disorders has been widely debated. It has been reported that noise from wind turbines can lead to such symptoms as dizziness, nausea, the sensation of ear pressure, tinnitus, hearing loss, sleeping disorders, headache and other symptoms. Additionally, the term ''Wind Turbine Syndrome'' has been coined to describe the association of these symptoms to wind turbine noise exposure [1–6]. However, the level of scientific evidence in wind turbine research, evaluated by several comprehensive reviews, is poor, as most of the research used to reach the conclusions found in these studies has been based on mere case reports and other similar studies [7–11]. It has also been argued that most of the symptoms supposedly related to wind turbine noise exposure could be psychosomatic ones stemming from a fear of wind turbines rather than any real adverse health effects [12]. Furthermore, reports in the scientific literature which have tried to establish a causal relationship between wind turbine noise and adverse health effects have tended to initiate heated debates between the authors and their readers, with critics often claiming that there was an insufficient amount of high quality evidence of a direct-dose response relationship between the noise exposure and the symptoms [9, 13, 14].

In order to shed light on the question of causation, researches frequently seek a statistically significant dose-response relationship. Statistically significant relationships between exposure and symptoms may not be shown to be causal without knowing if there is a dose-response relationship. The aim of the present study is to systematically analyse the literature and conclude if there is any evidence to support these theories of adverse health effects caused by exposure to wind turbines.

Guidelines, Recommendations and Requirements for wind turbine noise

Noise from wind turbines is generated to a lesser degree by the rotory hub; however, virtually all other wind turbine noise is generated by the downward movement of the rotating blades which result in the characteristic audible swishing pulses [15–17]. During the night these swishing pulses can become more dominant, and pulses from several wind turbines in the same vicinity can propagate in phase and lead to increased pulse sounds with increased sound pressure levels of 5 dB [18]. This amplitude modulation of the sound can also become more prominent under certain meteorological conditions [19]. Furthermore, noise from wind turbines will increase with any increase in the ambient wind speed [20, 21]. This amplitude modulating sound is often considered to be the most annoying aspect of wind turbine noise, and this has led to suggestions of incorporating the level of amplitude modulation as a measurement parameter for setting regulations for these noise measurements [22–24].

Noise is often measured as A-weighted equivalent sound pressure levels (L_{Aeq}) during a certain period of time. To then calculate L_{den}, 10 dB is added to the A-weighted equivalent sound pressure levels (L_{Aeq}) during the night and 5 dB is added to these noise levels during evening periods. If L_{Aeq} is constant throughout the day and night, L_{den} can be calculated by the addition of 6.4 dB to the measured L_{Aeq} [25]. L_{den} is measured at a height of 10 meters, and it is dependent on the wind speed, the landscape and the turbine type [25]. In several countries wind turbine noise has been limited to a maximum allowable level of L_{Aeq} at 35–44 dB, depending on the given wind speed and the special noise sensitivity in areas with low levels of background noise [9, 21, 26–28]. In Denmark, for example, the maximum level - L_{max}, corresponding to a L_{Aeq} of 42–44 dB or 37–39 dB in noise sensitive areas, is dependent on the wind speed (8 or 6 m/s respectively) [29]. In general noise levels in residential areas are calculated from noise prediction models; however, these noise prediction models have often been found to over-predict wind turbine noise levels at the point of the receivers [30].

Infrasound is considered to be sound of frequencies below 20 Hz, and low-frequency sound is considered to be sound between 20–200 Hz. Infrasound originates from many different sources in the environment including compressors, ventilation and traffic noise [31]. It has been demonstrated that wind turbines can cause low-frequency sound exposure of above 20 dB in the homes of close neighbours [32]. Most countries do not have regulations regarding infrasound and low-frequency noise from wind turbines, with the exception of Denmark where low-frequency sound in the 10–160 Hz range is limited to an A-weighted level (L_{pALF}) of 20 dB [29].

Methods

The supporting PRISMA checklist is available as supporting information; See Checklist S1 .

The objective of the present study was to analyze the literature systematically, and to determine if there was any statistical evidence of adverse health effects from exposure to wind turbine noises. The literature reviewed here included literature from both peer-reviewed scientific sources as well as internet sources which were not necessarily peer-reviewed. All types of studies investigating any relationship between wind turbine noise exposure and health-effect outcomes were included in the systematic review. Furthermore, with the purpose of aiding in the analysis and interpretation of the findings of the systematic review, a separate review of issues related to wind turbine exposure was also conducted. Focus was given in particular to finding additional technical information with respect to the size and character of wind turbine noise, as well as information regarding documented community opinions of wind turbines.

A PubMed search was conducted using the search string: wind turbines OR wind turbine OR wind farm OR wind farms. Additionally, a Web of Science search was conducted using the search string: (wind turbines OR wind turbine OR wind farm OR wind farms) AND (health OR noise OR annoyance OR tinnitus OR vertigo OR epilepsy OR headache) (Figure 1). Both database searches were performed again for a final time on the 9th of June 2014, and included all relevant reports published up until that time. No limits in language were used in the database searches.

Duplicates of articles were removed, and the titles and abstracts of all records were screened. Articles were then selected for full-text review, dependent upon whether the content of the article concerned wind turbines and related health effects on humans. Of the articles selected for full-text review, reported health effects included noise annoyance and psychological aspects related to the opinions of communities regarding wind turbine noise, as well as specific studies exploring noise exposure from wind turbines. Only articles in English, German and Scandinavian languages were selected for full-text review. Articles containing specific environmental issues and problems related to biology and wild life, as well as more technical articles regarding wind turbine mechanics, were not selected for full-text review.

Additionally, Google Scholar (http://scholar.google.dk/) was searched with the same search string previously used for the Web of Science search (See Figure 1). Articles from all years were retrieved in the initial search, while all patents and citations were excluded. (Google Scholar is a search engine that shows the 1000 most relevant web-resources). Several additional searches were also performed with limitations set to articles from 2014, 2013–2014 and 2010–2014. Based on these searches, publications were selected for full-text review based on the same criteria as described above. The final search was performed on the 9th of June 2014. Following this selection procedure, duplicates of previously retrieved articles were removed.

Google Scholar may not necessarily retrieve all relevant sources of, in particular, non-peer reviewed sources, and it was also evident from searches in Google Scholar that several additional websites contained a large number of relevant publications. Therefore, publications listed at the following websites: https://www.wind-watch.org/, http://www.windturbinesyndrome.com/and http://waubrafoundation.org.au/were also searched and screened by using the same selection procedure as described above. Publications were only retrieved for full-

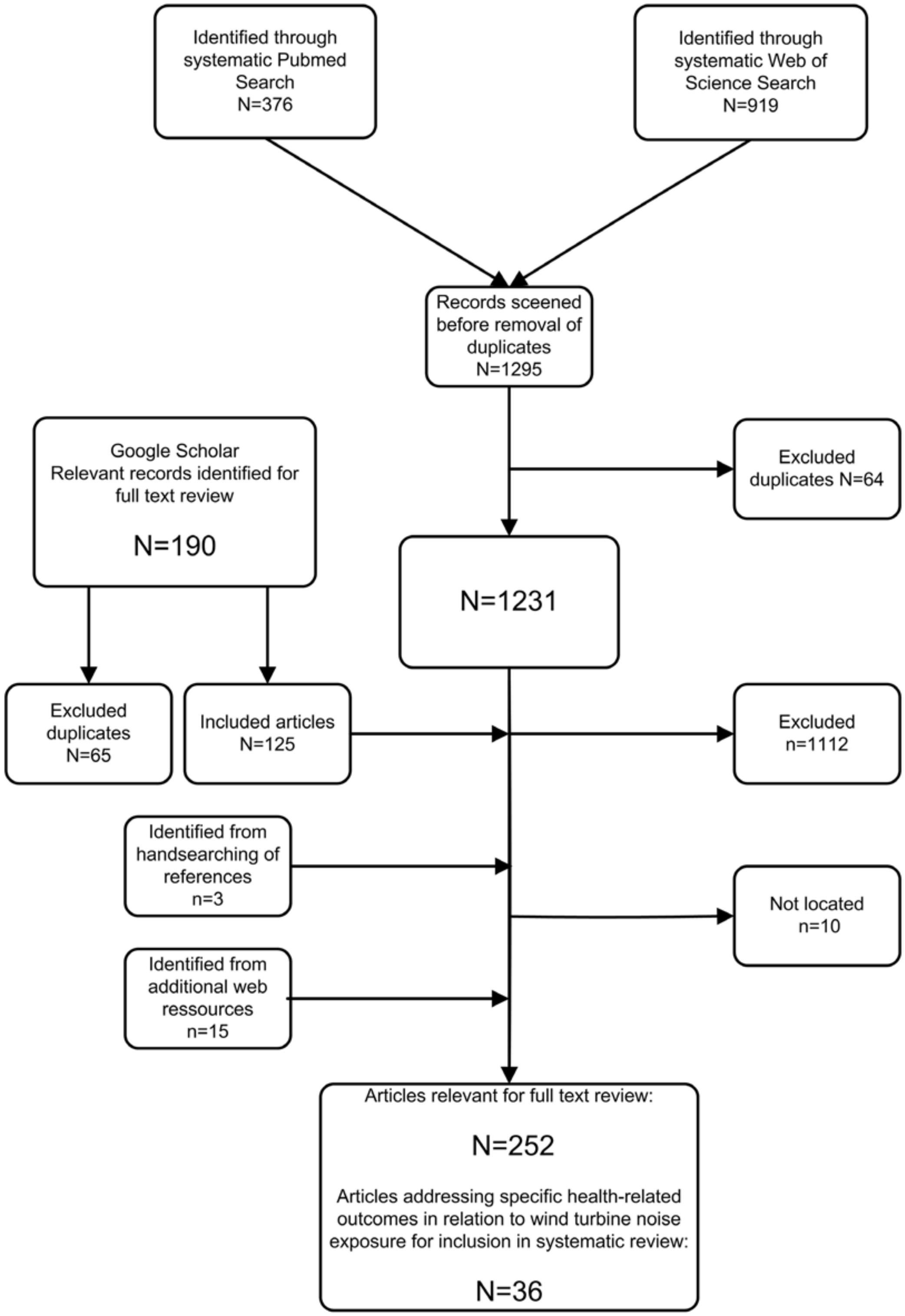

Figure 1. Search strategy for relevant publications.

doi:10.1371/journal.pone.0114183.g001

text review, however, if they were not already retrieved in the previous searches with PubMed, Web of Science and Google Scholar.

The reference lists of selected publications were also searched for additional articles pertaining to health-related issues believed to be related to wind turbine noise.

All articles investigating the association between wind turbine noise exposure and any suspected health-related outcomes were then identified from among the articles selected for full-text review, and these identified articles were included in the systematic review. Originally the systematic review had only attempted to investigate and, if possible, provide evidence for any association between wind turbine noise exposure and health-related outcomes such as noise annoyance, sleep disturbance, any kind of psychological distress including mental and concentration problems, tinnitus, vertigo, headache and epilepsy, as these symptoms had been reported in case reports as resulting from wind turbine exposure. The data extraction was, however, not limited to these variables. Other health-related outcomes could be included in the review as well, should these variables later be identified as important during the review process. Thus, information regarding any evidence of health-related effects associated with wind turbine noise exposure was extracted from the included articles by one reviewer and confirmed by the second reviewer. Disagreements were resolved by discussion of the selected articles. Duplicate publications from the same study population were included in the study to present additional evidence for health-related effects related to wind turbine noise, if this evidence was not previously reported in other publications. It was also specified when several publications reported data from identical study populations. Extracted information from different studies addressing similar health-related outcomes related to wind turbine exposure were summarized in tables where study differences in terms of study populations and the exposure assessment were described. It was stated when a specific association between wind turbine noise exposure and a health-related outcome was found to exist.

No limiting criteria regarding the quality of the research was used initially in the selection process of the articles for the systematic review of health-related effects in relation to wind turbine noise exposure. Any potential risk of bias identified in the selected studies was assessed afterwards and reported specifically as a part of the quality assessment of the included studies in the systematic review.

Results

Literature searches from PubMed and the Web of Science identified 1231 publications after the removal of duplicates (Figure 1). Only articles related to wind turbines and health-related effects were selected for further full text review, and, for this reason, 1112 publications were excluded.

In total 119 publications from the Web of Science and PubMed databases and additional 125 publications identified from Google Scholar were selected for further evaluation (Figure 1) after excluding duplicates. Fifteen publications were added from Internet sources regarding wind turbines. Additionally, three publications were included after reviewing the reference lists of the selected publications, and 10 of the selected publications could not be retrieved. Thus, a total of 252 unique publications were included in the full-text review. Thirty-five publications investigating health-related outcomes of exposure to wind turbines were identified from the systematic literature search to be included in the systematic review [1, 33–66]. In addition, one article that calculated the expected annoyance of sound exposure to wind turbines based on previous results from Janssen et al. 2011, was also included [33, 67]. Thus, 36 publications fulfilled the inclusion criteria and were included in the systematic review. Two publications by Janssen et al. (2009, 2010), two by Pedersen et al. (2006, 2008), and one publication by Nissenbaum et al. (2011) were published in conference proceedings. The results in these publications were identical to the meta-analysis published by Janssen et al. 2011, and to the studies from Sweden and the Netherlands published by Pedersen et al. (2007, 2009) and to the study from the U.S.A. published by Nissenbaum et al. (2012). Thus, only Janssen et al. 2011, Pedersen et al. 2007 and 2009 and Nissenbaum et al. 2012 were used in the systematic review [33, 37, 39, 40, 58–62]. Likewise, only Pawlaczyk-Luszczynska et al. 2014 was used for this review since Pawlaczyk-Luszczynska et al. 2013 reported identical results in a conference proceeding [46, 63]. As such, 30 publications, after the exclusion of the aforementioned six conference publications, were identified as specifically investigating health-related outcomes of exposure to wind turbine noise.

Four of these 30 publications were identified as case series [1, 64–66]. Case series studies report adverse health effects which are hypothesized to be a result of exposure to wind turbines. Case studies in general may be affected by selection and information bias which may also be true for the selected case studies in this review. This means, that these case studies may be biased and, as such, contribute fairly week evidence towards forming any conclusions about causation. The studies can, however, be hypothesis-generating in terms of a causal relationship.

The remaining 26 publications that investigated a relationship between exposure to wind turbine noise and adverse health effects were cross-sectional studies. These studies used a stratified approach where subjects with low or no exposure were compared to subjects with high exposure to wind turbine noise [36–56, 67]. One of these studies with a limited sample size (11 exposed, 10 unexposed) used longitudinal health data related to wind turbine noise exposure [57]. Three of these studies were meta-analyses of previous cross-sectional studies [33–35]. With such cross-sectional studies it is thereby possible to assess a dose-response relationship between exposure to wind turbine noise and adverse health effects. Selection bias and information bias, however, will likely occur. Cross-sectional studies can, therefore, not be used to determine any specific causal relationships.

Thus, the evidence presented in this systematic review had to rely on case-series reports and cross-sectional studies. Meta-analyses could increase the sample size, but the level of evidence was still dependent on the original cross-sectional studies included in the meta-analysis.

None of the included studies investigated the relationship of health effects and exposure to low-frequency noise or infrasound; however, infrasound and low-frequency noise emission from wind turbines were measured and studied in a number of the publications retrieved from the 252 articles initially selected [2, 32, 68–77].

Health effects related to infrasound and low-frequency sound exposure from wind turbines

Infrasound

While no study conducted so far has examined the potential adverse health effects related to specific infrasound exposure, this subject has been widely debated as a possible explanation for suspected health effects of wind turbine noise exposure even when the infrasound is not audible [1, 37, 42, 45, 46, 52, 53, 66]. Infrasound in general may be audible at high sound pressure levels; however, infrasound from wind turbines is subaudible unless one is very close to the wind turbine rotor [68, 72, 78]. Wind turbine infrasound levels for frequencies of up to 20 Hz were measured between 122–128 dB near wind turbines using G-weighting as recommended for the measurement of infrasound [32]. At further distances, however, between 85–360 meters from other wind turbines, G-weighted sound pressure levels were measured between 61–75 dB [32, 69]. In addition, measurements taken from large wind turbines above 2 MW at distances ranging between 68–1000 meters gave an infrasound exposure of between 59–107 dB(G), as summarized in a review by Jakobsen [70]. Smaller wind turbines below 2 MW measured at 80–500 meters distance were recorded as giving an infrasound exposure of 56–84 dB(G) [70]. Similar infrasound exposures were measured at 350 meters from a gas-fired power station (74 dB(G)), at 70 meters from major roads (76 dB(G)), at 25 meters from the waterline at the beach (75 dB(G)) as well as at 8 kilometres inland from the coast (57 dB(G)) [69]. Even when the infrasound exposure from wind turbines is not audible outdoors, infrasound in the 5–8 Hz range can still lead to a rattling of doors and windows which is audible indoors and can be an annoyance to those living in close proximity to wind turbines [73].

Wind turbines do emit infrasound, but it remains unknown if exposure to infrasound from wind turbines can lead to adverse health effects. It has also been hypothesised that infrasound may contribute to the amplitude-modulated nature of wind turbine noise which can then contribute to the perception of this noise [79, 80].

Some physiological changes have, however, been demonstrated in humans exposed to infrasound as shown in one functional MRI study where 110 dB infrasound at a 12 Hz tone activated areas of the primary auditory cortex in the brain [81]. Infrasound at 6 Hz and 130 dB was also able to affect Distortion Product Otoacustic Emissions (DPOAE) in humans [82]. The exposure in these studies was above 100 dB(G) and may be audible to some individuals. Of further note, it has been demonstrated in a double-blinded study that patients with Meniere's disease experience significant relief or even curative effects by using a Meniett pressure device which applies pressure of sinusoidal pulses of 6 Hz [83].

Some evidence suggests that even inaudible sound may affect the delicate structure of the ear and the vestibular organ. A recent review of several animal studies demonstrated that small physiological changes could be detected in the cochlear outer hair cells when these animals were exposed to infrasound. The outer hair cells of the cochlea were more sensitive to infrasound compared to the inner hair cells [84]. There exists as yet no human data comparable to that of these animal studies, so it is therefore still unclear if such theoretical affections of the inner ear structures can explain why some individuals have symptoms like tinnitus, vertigo and Meniere's disease [4].

Exposure to inaudible infrasound from wind turbines has also led to speculations that adverse health effects resulting from this exposure are perhaps psychological in nature [12]. In two recent randomized and controlled psychological experiments 54 and 60 subjects respectively were randomized into groups with either positive or negative expectations towards wind turbine noise and then informed separately about either the potential benefits or the supposed harmful effects and symptoms related to wind turbines and infrasound exposure. The subjects were shown either positive or negative videos about wind turbines and related health effects prior to the experiments. These studies demonstrated that the subjects randomized to the groups with negative expectations reported significantly more symptoms both when exposed to infrasound ($p<0.01$) and to sham infrasound (no sound) ($p<0.01$), as well as after exposure to audible wind turbine noise compared to the baseline ($p<0.001$) [85, 86]. Thus, these experiments support the hypothesis that a subset of the population conditioned to dislike wind turbines may be more sensitive to adverse effects after infrasound exposure itself or wind turbine noise in general [85, 86]. It should be noted that discrete sound exposure periods in a listening room may not be comparable to wind farm noise; however, positive or negative expectations towards wind turbine noise or any other noise would seem to affect self-reported health outcomes. Such psychological expectations may influence the opinion of a subset of the population who will then fear the potential health effects of wind turbines [8]. Furthermore, there can be a general resistance in the population towards a nearby planned location of wind turbines close to residential areas. This phenomenon has been termed "Not In My Back Yard (NIMBY)", and it relates to the resistance often seen when a wind farm project or any other project (e.g. airports, highways, chemical plants) is planned near a residential area, regardless of whether or not that project is actually harmful or just perceived to be so [87, 88].

Thus, it remains unknown if exposure to infrasound from wind turbines does cause adverse health effects or if these potential health effects are the results of psychological mechanisms. Moreover, no studies so far have specifically examined the relationship between G-weighted sound pressure levels of infrasound with wind turbine noise exposure and health effects, and, likewise, no studies have demonstrated an influence of infrasound on specific vestibular diseases.

Low-frequencies

Wind turbines have been shown to produce a relatively large amount of noise in the low-frequency spectrum [32, 89]. Wind turbine low-frequency noise can be more intense compared to other well-known sources of low-frequency noise such as road traffic noise and aircraft noise [89]. Furthermore, the low-frequency noise can increase with an increase in turbine size [32]. In fact, this noise is not particularly different when compared to other known sources of low-frequency noise from road traffic noise and industry [29].

Sound pressure levels of nine wind turbines (2.3–3.6 MW) were measured in Denmark, and the distances which equalled L_{Aeq} of 35 dB were calculated. The distances were found be between 629–1227 meters from the rotor of the wind turbine. At this distance the level of the infrasound was 54–59 dB(G) and the low-frequency noise was between 26.7–29.1 dB(A). The highest octave band was found to be 250 Hz, and this means that low frequencies play an important role regarding the noise measured in neighbouring areas of wind turbines. Half of the measured room/wind turbine combinations actually demonstrated that the low-frequency limit of 20 dB set by Danish legislation was exceeded [32]. Furthermore, noise generated by wind turbines can lead to ground vibrations [68, 71]. These ground vibrations are, however, small since walking or running 50 meters from the measurement point, elicited larger outdoor vibrations than a wind turbine located 90 meters away [68]. However, the perception of sound and sensation of airborne vibrations from i.e. wind turbines has been demonstrated to be higher indoor compared to outdoor and the vibrations indoor were detected as recurrent low-frequency pulses which are likely to be more annoying compared to a more constant noise [2, 71, 90].

Vibrations from low-frequency sounds are reported to be the cause of vibro-acoustic disease (VAD) [91]. VAD is reported to happen when long-time exposure to low-frequency sounds occurs [92, 93]. However, VAD has not yet generally been accepted as a clinical disease by the medical community as reviewed by Chapman and St George [91].

Relationship between noise annoyance and sound exposure

Noise annoyance is not directly studied as a primary outcome in most of the case studies; however, it is evident from these studies that many subjects complain about noise from wind turbines [1, 64, 66].

Several reasons can explain why wind turbine noise probably causes more annoyance than other sound sources. Wind turbines are often placed in areas where background noise levels are low. People living in these areas may have sought out tranquillity and have likely accustomed themselves to the silence, which may influence their annoyance level regarding unwanted sounds in their environment [5, 94]. Furthermore, any changes in their surroundings or their

Table 1. Relation between annoyance and sound exposure to wind turbines.

Studies	N	Dose- response-relationship	Effects	Other factors influencing annoyance
Jansen et al. [33] 2011 (meta analysis of Pedersen et al. 2004,2007,2009 [38–40].	1820	Yes	Highly exposed subjects more annoyed compared to less exposed subjects.	Noise sensitive subjects (↑)Visible wind turbines (↑)Age (↑)Economic benefits (↓)
Pedersen 2011 [35]. (A subpopulation of same study populations as Jansen et al. 2011 [33]).	1755	Yes	Highly exposed subjects more annoyed compared to less exposed subjects.	Economic benefits (↓) – analyses were adjusted for economic benefits, but only in analyses with data from Pedersen et al. 2009.
Pedersen and Larsman 2008 [34] (meta-analysis of Pedersen et al. 2004 and 2007 [38, 39].	1095	Yes	Highly exposed subjects more annoyed compared to less exposed subjects. Effect was independent on terrain.	Negative evaluation of wind turbines (↑)Visual attitude towards wind turbines for subjects who could see the wind turbines and to a lower degree for subjects who could not see the wind turbines (↑)Increased vertical visual angel is correlated to wind turbine noise and annoyance (↑)
Pedersen et al. 2009Bakker et al. 2012 [36, 40, 41].	725	Yes	Highly exposed subjects more annoyed compared to less exposed subjects.	Noise sensitive subjects (↑)Visible wind turbines (↑)Economic benefit (↓)Build-up area opposed to rural area without main road (↑)Rural area with main road (↓)
Pedersen et al. 2004 [38, 41, 47].	341	Yes	Highly exposed subjects more annoyed compared to less exposed subjects.	Noise sensitive subjects (↑)Negative attitude to visible wind turbines (↑)Negative attitude to wind turbines in general (↑)
Pedersen et al 2007 [39, 41, 47].	754	Yes	Highly exposed subjects more annoyed compared to less exposed subjects.	Noise sensitive subjects (↑)Attitude to visible wind turbines (↑)Attitude to wind turbines in general (↑)
Pawlaczyk-Luszczynska et al. 2014 [46].	156	Yes	Highly exposed subjects more annoyed compared to less exposed subjects.	Noise sensitive subjects (↑)Attitude to visible wind turbines (↑)Attitude to wind turbines in general (↑)Sensitivity to landscape littering (↑)Negative self-assessment of physical health (↑)Wind turbines were found to be the most annoying sound source.

Table 1. Cont.

Studies	N	Dose- response-relationship	Effects	Other factors influencing annoyance
Aslund et al. 2013 [67]. Based on calculations from Pedersen et al. 2009 and Bakker et al. 2012 and Jansen et al. 2011 [33, 36, 40].	8123 theoretically exposed subjects. 522 are participating receptors.	Yes (Dose-response relationship derived from other studies).	Highly exposed subjects close to wind turbines calculated to be more frequently annoyed and very annoyed.	Participating residents in wind farm projects (↑)Annoyance outdoor calculated to be higher than annoyance indoor.
Shepherd et al. 2011 [42].	39 subjects. 158 controls.	Not related to sound – related to distance.	Annoyance not directly compared between subjects and controls.	Annoyance decreased perceived general health as well as physical, social and environmental quality of life scores for the control group only. Subjects reported, however, lower environmental quality of life scores compared to controls.
Kuwano et al. 2013 [43].	747 subjects. 332 controls.	Not related to sound.	Proportion of annoyed subjects higher in wind turbine exposed subjects	All kinds of noise sources increased annoyance in both groups. Subjects in the wind turbine group found wind turbines as the most annoying sound source.
Yano et al. 2013 [44].	747 subjects.	Yes	Highly exposed subjects more annoyed compared to less exposed subjects.	No difference in dose-response curves between cold and warm areas. Living near the sea (↓). (Waves may mask wind turbine sounds). Noise sensitivity (↑)Landscape disturbing (↑)Environmental interest (↑)
Morris 2012 [50, 51].	93 households.	Not related to sound.	56% of households are annoyed during night time within 0–5 km. from the wind turbines compared to 40% of households living within 0–10 km from wind turbines.	No influencing factors were investigated.
Schafer 2013 [54].	23 households.	Not related to sound.	66% of subjects affected by noise at night.	No influencing factors were investigated.
Schneider 2012 [55, 56].	23 households, 25 household in follow-up.	Not related to sound.	85.7%/ (87.7% in follow-up study) were disturbed from day time noise. 100% from night time noise in follow-up.	No influencing factors were investigated.
Thorne 2012 [52].	25	Not related to sound, but sound levels measured.	91% were annoyed indoor.	No influencing factors except living near wind turbines were investigated.

doi:10.1371/journal.pone.0114183.t001

environment will probably introduce a level of annoyance in the case of at least some individuals [5, 8].

As shown in Table 1, which summarizes studies on annoyance and wind turbine noise, a dose- response effect of noise exposure and noise annoyance has been demonstrated. Two studies (754+351 subjects) were conducted in Sweden, one study in the Netherlands (725 subjects), one study in Poland (156 subjects) and one study in Japan (747 subjects) with different questionnaires assessing noise annoyance used than those in the aforementioned studies from Sweden, the Netherlands and Poland [38–40, 46]. All five studies demonstrated a significant relationship between A-weighted sound exposure and wind turbines and annoyance [38–40, 44, 46]. All studies were cross-sectional studies, and they used a questionnaire-based survey which was combined with either direct sound measurements or estimated sound emission levels outside the subjects' dwellings [38–40, 44, 46]. All studies asked for subjective answers regarding the degree of annoyance towards different sound sources to mask the true purpose of the questionnaire [38–40, 44, 46]. In general, the selection of geographical areas in which to conduct these studies was quite large, encompassing several different areas, thus helping to limit selection bias. In the study from Japan, for example, a control group of 332 subjects not exposed to wind turbines was also included for comparison. While wind turbine noise was found to be the most annoying sound source in the exposed group, traffic noise was perceived as the most annoying sound in the control group [43].

Additionally four studies ranging from 23 to 93 households were conducted near four different specific wind farms in Australia (Table 1) [50–52, 54–56]. These studies reported that 40 to 91% of households were annoyed. Response rates between 23 to 40% were reported in only two of the studies [50, 51, 55, 56].

The studies from Sweden and the Netherlands were used in a meta-analysis where L_{den} was calculated from the measured L_{Aeq} reported in the original studies [33]. To calculate L_{den} an average correction factor of 4.7 dB was used as earlier suggested by van den Berg (2008) to account for differences in wind conditions and different terrains in the different studies. By calculation of L_{den} this study could compare the degree of annoyance in relation to L_{den} and this value could be compared to other well-known sources of environmental noise such as road traffic noise and noise from airports. The meta-analysis showed that noise from wind turbines was perceived as more annoying compared to noise from road traffic, airports and trains at similar values of L_{den} [33]. Age, general noise sensitivity and visual disturbance by wind turbines were positively associated with annoyance whereas economic benefit was significantly negatively associated with annoyance. The data from the two Swedish studies were also combined in an additional analysis and it was demonstrated that noise annoyance from wind turbines was significantly correlated to swishing, whistling, resounding and pulsating sounds from wind turbines [34]. Furthermore, a model for the dose-response relationship between sound exposure and the risk of high annoyance due to sound exposure to wind turbines was established [33]. The degree of annoyance has in general been reported to be between 10–45% of the population if the sound exposure was above 40 dB(A) but less than 10% of the population will be annoyed if the sound exposure is below 35 dB(A) [38–40]. In a planned wind farm project where the noise exposure was calculated based on the results from the meta-analysis by Janssen et al., 17 to 18% of the 8123 recipients living within a distance of 1 km from the wind turbines were expected to be rather or very annoyed when outdoors [33, 67]. On the other hand, it was demonstrated in a field study from the United States that the degree of annoyance was only 4% in a population living within a distance of approximately 600 meters to wind turbines [95].

Experimentally it has been shown that wind turbine noise does not differ substantially from traffic noise when the wind turbine noise is not known of in advance [96]. However, wind turbine noise is poorly masked by road traffic noise unless the exposure to wind turbine noise is at an intermediate level (35–40 dB(A)) [97, 98]. Wind turbine noise has distinctive features which allow for detecting that type of noise from amongst other sound sources at low signal-to-noise ratios. This means that focussing on the sound can increase noise annoyance [96]. It has been shown that wind turbine noise can be masked with natural background noise. In order to mask the sound completely the background noise needs to exceed the noise from the wind turbines with 8–12 dB [99]. An increase of background noise with 8–12 dB is not practical, but the perceived loudness of noise and annoyance from wind turbines is reduced if the background noise is at the same level or higher than the wind turbine noise [99, 100].

It was calculated that 330 dwellings in the Netherlands were exposed to wind turbine noise exceeding L_{den} by as much as 50 dB and that 440.000 inhabitants were exposed to L_{den} above 29 dB. Of these 440.000 inhabitants, 1500 were expected to be severely annoyed [89]. The estimation of this noise exposure at different dwellings may, however, have been altered by atmospheric changes, so it was further calculated that the sound exposure could be up to 5 dB lower and 10 dB higher than predicted under neutral conditions. It is generally believed that noise limits for wind turbines should be set at a level where fewer than 10% of exposed people are annoyed. A limit of 45 dB in the Netherlands has been estimated to annoy 5.2% of the exposed inhabitants [89].

Relation between wind turbine noise exposure and sleep disturbance

Table 2 summarizes studies investigating the relationship between noise exposure to wind turbines and sleep disturbance. Reports from case studies indicated that many subjects living near wind turbines complained of sleep disturbance [1, 64–66]. These results were supported by the finding of a dose-response relationship between self-reported sleep disturbance and A-weighted noise exposure in three out of four larger epidemiological studies from Sweden, the Netherlands and Poland [35, 36, 46]. Furthermore, a disturbed sleep was also found to be higher among exposed subjects compared to unexposed control subjects in three studies from Japan (754 subjects, 332 controls), the U.S.A. (38 subjects, 41 controls) and New Zealand (39 subjects, 158 controls) [37, 42, 43]. The Pittsburg Sleep Quality

Table 2. Relation between sound exposure to wind turbines and sleep disturbance.

Study	N	Dose- response-relationship	Effects	Other factors influencing sleep
Nissenbaum et. al. 2012 [37].	38 subjects near wind turbines.41 controls far from wind turbines.	Not related to sound but sleep scores related to distance.	Subjects near wind turbines had worse sleep (Pittsburg Sleep Quality Index and Epworth Sleepiness Scale score) compared to subjects far from wind turbines.	
Bakker et al. 2012 [36].	725	Yes	Highly exposed subjects reported more frequent sleep disturbances.	Sleep disturbance higher in urban areas where subjects were disturbed by traffic noises, people leaving the disco, animals.
Pedersen et al. 2011 [35].	1755	Yes/No	Highly exposed subjects reported more disturbed sleep in 2 out of 3 studies.	Pedersen et al. 2004 and 2009 did report an association between sound exposures and sleep disturbance. Pedersen et al. 2007 did not find an association.
Pawlaczyk-Luszczynska et al. 2014 [46].	156	Yes	Highly exposed subjects suffered significantly more of insomnia ($p<0.05$).	Negative self-assessment of physical health (↑) Wind turbines were found to be the most annoying sound source.
Kuwano et al. 2013 [43].	747 subjects.332 controls.	Not related to sound – related to distance.	Proportion of subjects with affected sleep was slightly higher in wind turbine exposed subjects.	All kinds of noise sources increased sleep disturbance in both groups. Subjects in the wind turbine group found wind turbines as the most disturbing sound source.
Shepherd et al. 2011 [42].	39 subjects.158 controls.	Not related to sound – related to distance.	Perceived sleep quality poorer in subjects (wind turbine exposed) compared to controls (not exposed).	Worse sleep with increased noise sensitivity in wind turbine exposed. General health, physical and psychosocial health increased with better perceived sleep quality.
Krogh et al. 2011 [49].	102 subjects with health problems.	Not related to sound.	Sleep disturbance more frequently reported, but not significantly ($p=0.08$) different in subjects living close to wind turbines compared to subjects living further away.	Excessive tiredness was reported significantly increased ($p=0.03$) in subjects living within 350–673 meters from wind turbines compared to subjects living between 700–2400 meters from wind turbines.
Lane 2013 [57].	11 exposed.10 unexposed.	Increased awakenings were related to sound levels above 45 dB(A).	Slightly but not significantly worse sleep parameters in the exposed group measured with actigraph.	Reasons of awakening were not related to wind turbine noise. Use of the bath-room by a child or partner were the most commonly reported sources of awakening. No correlation between distance to wind turbines and sleep efficiency were found. Overall uneven correlation between subjective and objective sleep parameters.
Paller 2014 [45].	396	Not related to sound but sleep scores related to distance.	Subjects near wind turbines had worse sleep (Pittsburg Sleep Quality Index) ($p<0.01$) compared to subjects far from wind turbines.	Analyses were controlled for age, gender and county.
Harry 2007 [66].	42	Not related to sound.	More than 70% of cases reported impaired sleep.	No control group. Cases are just reported to live near wind turbines.
Iser 2004 [65].	19	Not related to sound.	8/19=42% reported disturbed sleep.	No control group. Cases were just living near wind turbines.
Morris 2012 [50, 51].	93	Not related to sound.	39% of households had disturbed sleep within 0–5 km. from the wind turbines compared to 29% of households living within 0–10 km from wind turbines.	No influencing factors were investigated.
Wind Concerns Ontario [64].	112	Not related to sound.	48% reported sleep disturbance.	No influencing factors except living near wind turbines were investigated.
Schafer 2013 [54].	23 households.	Not related to sound.	51% of subjects affected by sleep disturbance.	No influencing factors except living near wind turbines were investigated.

Table 2. Cont.

Study	N	Dose- response-relationship	Effects	Other factors influencing sleep
Schneider 2012 [55, 56].	23 households. 25 households in follow-up.	Not related to sound.	78.5% had disturbed sleep. 100% had disturbed sleep in follow-up study.	No influencing factors except living near wind turbines were investigated.
Thorne 2012 [52].	25	Not related to sound, but sound levels measured.	92% noted a change in sleep patterns.	No influencing factors except living near wind turbines were investigated.
Pierpont 2009 [1].	38 subjects from 10 families.	Not related to sound.	86% reported disturbed sleep.	No influencing factors except living near wind turbines were investigated.
Phipps [53].	614 households.	Related to distance.	Disturbed sleep was reported by 42, frequently disturbed sleep by 21 and 5 were affected most of the time.	No influencing factors except living near wind turbines were investigated.

doi:10.1371/journal.pone.0114183.t002

Index (PSQI) was used as an outcome measurement in the American study and in studies, from Australia (25 subjects) and Canada (396 subjects) [37, 45, 52]. The Australian study showed lower PSQI in the wind turbine group compared to known population values [52]. The studies from the U.S.A. and New Zealand both demonstrated a significant relationship between PSQI results and the distance to the wind turbines. Selection bias is a concern in these studies, however, as only a few selected wind farms were included in the studies, and the study from Canada had a response rate of only 8% [37, 42, 45]. Surveys of single wind farms in Australia, including 23–93 households within 0–10 km from the wind farms, investigated sleep disturbance along with the noise annoyance reported above. Twenty-nine to ninety-two percent of exposed households reported disturbed sleep in these studies (Table 2) [50–52, 54–56]. A larger survey from New Zealand (614 subjects) found only 42 subjects with disturbed sleep, but this study only investigated subjects living within 2–10 km to the wind farm. A study from Canada collected self-reported sleep disturbance complaints amongst other health-related outcomes. The data was collected from an Internet survey where subjects reported health data. This study found a significant relationship between the distance to wind turbines and undue tiredness ($p<0.03$). However, disturbed sleep ($p<0.08$) showed only a borderline significance in relation to the distance from the wind turbines [49].

Whereas most studies collected only subjective information about sleep disturbance, some studies attempted to also collect objective longitudinal sleep data over several nights. By using an Actigraph, sleep was monitored and related to noise measurements in the sleeping room. The study had a limited sample size; however, and no difference in objective sleep quality in relation to the noise exposure was observed in the 11 subjects exposed to wind turbines compared to the 10 unexposed subjects.

Noise from various environmental factors can affect sleep if the noise is pronounced at night [101].

Noise annoyance, self-reported sleep disturbance and psychological stress were all related to increasing sound pressure levels of wind turbines [35, 36, 42]. The impact of wind turbine noise was stronger for people living in rural areas with less background noise from other environmental factors. Sleep disturbance was only seen at high exposure levels above 45 dB(A), and sleep disturbance was significantly related to annoyance [36]. It was not possible, however, to conclude that sleep disturbance was caused directly by wind turbine noise, as other environmental noise sources could have played a role as well [36]. On the other hand, noise annoyance was not significantly correlated to sleep disturbance within a distance of two kilometers from the wind turbines, as had been reported in the study from New Zealand. Sleep, and ones physical and environmental quality of life were, however, affected in the wind turbine exposed group as reported above, and the authors suggested that both sleep disturbance and noise annoyance could have caused the observed degradation of health-related quality of life in the wind turbine exposed group [42]. Sleep disturbance was only weakly associated to A-weighted sound pressure levels in the first Swedish study and in the Dutch study if in- and outdoor noise annoyance were also included in the models. This demonstrates a correlation between noise annoyance and sleep disturbance and that noise annoyance may be a mediator of sleep disturbance or that sleep disturbance may induce annoyance [35].

Relation between wind turbine noise and other health parameters

Table 3 summarizes the findings from studies investigating the association between wind turbine noise and psychological distress. Psychological symptoms such as memory and concentration problems, anxiety and stress were frequently reported in case series of subjects exposed to wind turbine noise [1, 64–66]. Furthermore, noise annoyance was significantly associated to psychological distress [36]. Several studies measured the WHO-quality of life (WHOQOL) and found that physical health scores among wind turbine exposed subjects were lower than those of the unexposed controls as well as those of the general population (Table 3) [42, 48, 52]. The social and psycho-social scores in a study from New Zealand, however, did not differ between exposed and unexposed subjects in the initial investigation, and neither were these scores altered in a follow-up study two years later [42, 48]. Nonetheless, the general health of the turbine-exposed group was reported to be significantly lower when compared to controls [42, 48].

Another general health questionnaire (SF-36) was used to measure mental and physical component scores in wind turbine noise exposed subjects [37, 52]. Mental component scores were significantly lower with decreasing distance between the dwelling and the wind turbines, and the scores were also lower if they were compared to those of the general population [37, 52]. These studies may have been affected by selection bias, and the two wind farms investigated in the study by Nissenbaum et al. do not seem to be comparable in terms of exposure. The sound was measured at various distances from the wind turbines and then compared. It is evident that the sound levels measured at various distances were

Table 3. Psychological distress.

Study	N	Dose- response-relationship	Effects	Other factors influencing psychological distress
Bakker et al. 2012 [36].	725	Yes	Highly exposed reported psychological distress (General health questionnaire).	Annoyance influence psychological distress and in this case psychological distress is not predicted by sound-exposure.
Nissenbaum et al. 2012 [37].	38 subjects near wind turbines41 controls far from wind turbines.	Not related to sound but sleep scores related to distance.	Subjects near wind turbines had worse mental scores (Mental Component Score of SF-36) compared to subjects far from wind turbines.	
Shepherd et al. 2011 [42].	39 subjects.158 controls.	Not related to sound.	No differences found in psychological and social health-related quality of life (WHOQOL) questionnaire parameters.	
McBride et al. 2013– a follow-up of Shepheard et al. 2011 [42, 48].	Selected from 56 exposed houses and 250 control houses.	Not related to sound.	WHO-quality of life (WHOQOL) did not change in the follow-up period in the exposed group. The physical domain and general satisfaction with health scored significantly lower in the exposed group compared to the control group in the most recent study.	Amenity decreased significantly in the control group over time. Amenity was stable in the exposed group over time.
Harry 2007 [66].	42	Not related to sound.	More than 50% of cases reported anxiety and stress.	No control group. Cases are just reported to live near wind turbines.
Iser 2004 [65].	19	Not related to sound.	8/19=42% reported stress and likely symptoms.	No control group. Cases were just living near wind turbines.
Wind Concerns Ontario 2009 [64].	112	Not related to sound.	A majority reported stress, anxiety, excessive tiredness, depression.	No influencing factors except living near wind turbines were investigated.
Thorne 2012 [52].	25	Not related to sound, but sound levels measured.	Mental component score of SF-36 were much lower than expected from known population scores.	No influencing factors except living near wind turbines were investigated.
Pierpont 2009 [1].	38 subjects from 10 families.	Not related to sound.	93% reported memory and concentration problems.	No influencing factors except living near wind turbines were investigated.

doi:10.1371/journal.pone.0114183.t003

quite different in the two wind turbine parks. It is not, however, known if weather conditions or different terrains were the main causes of these differences, and it is also difficult to determine if the wind turbines were responsible for the sleep disturbance and low mental component scores in this study [37].

Associations between A-weighted sound pressure levels and subjective tinnitus and diabetes were demonstrated in one of the previous Swedish studies by Pedersen et al. [35]. As pointed out by the authors this could be a coincidental finding due to a multiplicity of logistic regressions since this finding was only demonstrated in one out of three studies investigating the association between sound exposure and tinnitus or diabetes. No significant associations between A-weighted sound pressure levels and headache, impaired hearing, chronic disease, cardiovascular diseases, high blood pressure, undue tiredness, irritability, tension, or stress were observed [35].

Case series studies of wind turbine noise exposed subjects often report headache, vertigo, tinnitus and hearing loss as frequent symptoms [1, 64–66]. Likewise, 8 out of 23 households reported headache and 4 out of 23 households reported dizziness in a study from a single Australian wind farm [54]. Self-reported symptoms like tinnitus, hearing problems, headache, stress and anxiety were not shown to be significantly related to the actual distance from the wind turbines, although one study did approach statistical significance for the symptom of tinnitus in relation to the distance from the wind turbines ($p<0.08$) [45, 49]. Symptoms of self-reported vertigo ($p<0.001$) were also increased for residents living closer to wind turbines in this study [45].

It is hypothesized that sound may affect the vestibular organ in the inner ear even at subaudible levels [84, 102]. A clinical test of vestibular function such as the vestibular-evoked myogenic potential (VEMP) test demonstrates that the vestibular system is sensitive to acoustic frequencies. Some vestibular diseases are known to be sensitive to change in pressure, such as perilymphatic fistula (PLF), superior canal dehiscence (SCD) and Meniere Disease (MD). The SCD (known as "a third window"), a defect in the superior semi-circular canal can give rise to Tullio phenomenon with sound-induced dizziness [103]. Such pressure-sensitive vestibular patients, however, have not as yet been evaluated with regard to wind turbine noise exposure even though such speculations have been made [84]. In our own clinical experience we have never seen PLF, SCD or MD patients complaining of aggravation of vestibular symptoms due to neighbouring wind turbines.

It has been further speculated that rotating wind turbine wings passing through the sunlight can induce epileptic attacks in sensitive subjects because the sunlight will be seen to flicker on the horizon. This phenomenon is known in the field of aviation medicine and can actually disqualify a pilot at the aeromedical health check-up due to the risk assessment associated with flying a turbo prop plane or helicopter. If light flickers at a frequency around 3 Hz there is a known risk that this can induce an epileptic attack in sensitive subjects [104]. The risk has been calculated as minimal in the case of large wind turbines which are unlikely to rotate fast enough to create an abruption of sun-light of more than three times per second, but there could be a risk with smaller wind turbines [105]. Shadow flickering is, however, a concern. It is often described in case series reports and studies from single wind farms and it may contribute to the overall annoyance from wind turbine exposure [1, 50, 51, 53].

Discussion

Noise from wind turbines results in significant annoyance for neighbours of wind turbines, and the level of annoyance is related to the A-weighted sound exposure [33–35, 38–40, 44, 46, 106]. It has been shown that the sound exposure from wind turbine noise increases noise annoyance by dose-responsive degrees, and this annoyance may be the primary mediating agent causing sleep disturbance and increased psychological distress [35, 36]. On the other hand, it is also possible that sleep disturbance may lead to increased annoyance. Self-reported sleep disturbance was found to be significantly related to the given sound exposure and more frequently reported from subjects living closer to wind turbines compared to subjects living further away [35–37, 42, 46, 49].

Annoyance was significantly related to psychological distress and the mental component scores of SF-36 were significantly affected in wind turbine exposed subjects in some studies [36, 37, 52]. However, no differences in the psychological and social health-related quality of life (WHOQOL) questionnaire parameters were observed in other studies [42, 48].

The quality of the studies included in this review is quite varied. There are five cross-sectional studies of reasonable sample size from which a dose-response relationship between sound exposure and health outcomes, particularly in relation to annoyance and sleep disturbance, was demonstrated [33–36, 38–41, 44, 46]. Selection bias and recall bias may, however, still have affected the outcomes of these studies, and it should be acknowledged that the sample groups in these studies were from many different wind turbine sites located in quite different geographical regions. Virtually all of the studies did point toward an association between wind turbine exposure and annoyance or sleep disturbance; however, one of the significant limitations of these cross-sectional studies is their inherent inability to evidence a clear causal relationship between exposure to wind turbines and health-related outcomes. It is therefore not known with certainty if the association between wind turbine exposure and health-related outcomes is caused by sound exposure, visual disturbance, economic aspects or something else. Cross-sectional studies are simply more explorative by nature.

Several studies investigated sleep disturbance and psychological distress in relation to an unexposed or low exposed control group [37, 42, 43, 48]. Sleep disturbance and psychological distress were only reported in self-reported questionnaires which increase the risk of introducing information bias into the study. Selection bias is a concern as well if the study population is not representative for an entire population of wind turbine exposed subjects. As such, selection bias as well as information bias related to the outcome are of concern and may potentially affect conclusions drawn by the studies. The study by Kuwano et al., however, was relatively large, investigating several different geographical areas of Japan. Thus selection bias would be less of concern in this study [43].

Several case reports have raised concerns that wind turbine noise may lead to various symptoms such as tinnitus, vertigo and headache. Until now, however, of these suspected symptoms, only tinnitus has been shown to have an association with A-weighted sound exposure, and that only in a single study out of three similar studies [35]. Neither was this association between wind turbine noise exposure and tinnitus supported in other studies either [45, 49]. These findings, as well as the finding of an association of A-weighted sound exposure to diabetes in one out of three similar studies, may be a result of multiple logistic regressions which can lead to spurious conclusions [35]. These results need to be confirmed by additional studies, before sufficient evidence can be established to support this association.

Most studies investigating a dose-response relationship between sound exposure and annoyance have used calculated values of L_{Aeq} or L_{den} based on model assumptions of sound propagation from wind turbines over distance [35, 38–40, 44, 46, 106]. It might be relevant to include another type of sound weighting rather than just the A-weighting in future studies. In fact G-weighted sound exposure was estimated in one study, but these values were not related to adverse health effects [46]. Furthermore, it has been demonstrated that other characteristics of the noise from wind turbines may correlate better with noise annoyance than the frequently used A-weighted metric [107, 108]. It seems evident that low-frequency sound exposure may increase with increasing turbine size [32]. However, others reports have demonstrated that the content of low-frequency sounds from wind turbines may not be particularly different compared to other environmental background noises [29]. Sound from several wind turbines may increase the sound pressure level of swishing pulses from the wind turbines, and this could be a factor relevant to the perceived noise annoyance [15, 20, 34, 71, 109]. It may therefore be relevant to focus future studies on serial monitoring of the sound exposure to include the nature of the amplitude-modulated sound and the low-frequency sound exposure in dwellings near wind turbines. It is known that wind turbine noise is quite dependent on the existing wind speed, and health-related effects of wind turbine noise could, therefore, be speculated to fluctuate depending on the different noise levels at different wind speeds [110]. It has also been suggested that G-weighed sound exposure levels could be used as well to demonstrate the exposure to infrasound [32]. An experimental study, however, found a possible link between the psychological expectations of symptoms following both actual infrasound and a sham sound exposure trial. In these trials a difference between the infrasound and sham sound could not be demonstrated [85]. These results should, however, be interpreted with caution, as laboratory conditions may not be comparable to the real life exposure of wind turbine noise.

One study has already measured objective sleep parameters in relation to sound exposure, but the sample size of the study was a limiting factor in reaching any conclusions [57]. Future studies should focus more on objective measurements of health-related disorders in relation to wind turbine noise exposure. Sleep could be monitored parallel with sound exposure measurements, and stress hormones could be measured as well. Objective measurements of health can be a valuable asset in combination with more subjective measurements when used in questionnaires regarding annoyance from wind turbine noise. Both types of data can be related to sound exposure measurements, and it could be relevant to report both A- and G-weighted sound exposure measurements as well as a thorough characterisation of exposure in the low-frequency area including the maximum peak values of the swishing pulses from wind turbines.

It is currently known that traffic noise exposure may increase the risk of cardiovascular disease and diabetes [111, 112]. The mechanism here could be increased stress and reduced quality of sleep which can increase the risk of cardiovascular diseases and diabetes [111, 112]. It is not yet known if wind turbine noise exposure during the night could result in identical health effects.

Furthermore, it should also be acknowledged that some patients might have symptoms of a functional somatic syndrome, describing persistent bodily complaints for which no objective findings supporting the symptoms can be found [113]. Many of the core symptoms of the wind turbine syndrome, such as tinnitus, headache, dizziness, nausea, sleep disorders and lack of concentration, as reported by subjects exposed to wind turbine noise, show a similar bodily distress as described in other functional somatic syndromes [1, 113]. Events like accidents and potential environmental health hazards can induce a functional somatic syndrome in certain individuals, and this may be potentiated by mass hysteria in the media [113, 114]. Issues of possible wind turbine health impacts have also been addressed by the mass media using emotionally-charged words and phrases such as "dread" and "poorly understood by science", and fright tactics like these may well have contributed to a mass hysteria regarding wind turbines [115, 116]. There are, nonetheless, numerous reports of many complaints related to wind turbine noise from various case studies [1, 6, 51, 55, 66]. These symptoms could be stress-related, and it is possible that these symptoms could occur as a result of sleep disturbance. On the other hand, these symptoms could be psychosomatic and explained as another sort of a functional somatic syndrome [12].

Conclusion

At present it seems reasonable to conclude that noise from wind turbines increases the risk of annoyance and disturbed sleep in exposed subjects in a dose-response relationship. There seems to be a tolerable limit of around L_{Aeq} of 35 dB. Logically, accepting higher limits in legislations may lead to increased numbers of annoyed subjects. It therefore seems reasonable to conclude that a cautious approach is needed when planning future wind farms. Furthermore, there is an indication that noise annoyance and sleep disturbance are related and that disturbed sleep potentially can lead to adverse health effects. These conclusions are, however, affected by a potential risk for selection and information bias even in the larger cross-sectional studies providing the current best evidence. The evidence for adverse health effects other than sleep disturbance is primarily supported by case-series reports which certainly may be affected by various sources of bias. Larger cross-sectional surveys have so far been unable to document a relationship between various symptoms such as tinnitus, hearing loss, vertigo, headache and exposure to wind turbine noise. One limitation causing this could be that most studies so far have only measured L_{Aeq} or L_{den}. An additional focus on the measurement of low-frequency sound exposure as well as a more thorough characterisation of the amplitude modulated sound and the relationship between objective and subjective health parameters could lead to different conclusions in the future. Finally, in regards to the objective measurement of health-related disorders in relation to wind turbine noise, it would be valuable to demonstrate if such health-related outcomes fluctuate depending on exposure to wind turbine noise.

Supporting Information

Checklist S1. PRISMA 2009 checklist.
doi:10.1371/journal.pone.0114183.s001 (DOC)

Acknowledgments

The authors want to thank the anonymous reviewers for critical inputs to this manuscripts. Jennifer Waugh, Joel Kammeyer and Lisa Michelle Norborg are acknowledged for their constructive comments regarding the language and readability of this manuscript.

Author Contributions

Conceived and designed the experiments: JHS MK. Performed the experiments: JHS MK. Analyzed the data: JHS MK. Contributed reagents/materials/analysis tools: JHS MK. Contributed to the writing of the manuscript: JHS MK.

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EXHIBIT
19

Review

Trends in Hearing
Volume 22: 1–10
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Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/2331216518789551
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A Review of the Possible Perceptual and Physiological Effects of Wind Turbine Noise

Simon Carlile[1,2], John L. Davy[3,4], David Hillman[5], and Kym Burgemeister[6]

Abstract
This review considers the nature of the sound generated by wind turbines focusing on the low-frequency sound (LF) and infrasound (IS) to understand the usefulness of the sound measures where people work and sleep. A second focus concerns the evidence for mechanisms of physiological transduction of LF/IS or the evidence for somatic effects of LF/IS. While the current evidence does not conclusively demonstrate transduction, it does present a strong prima facia case. There are substantial outstanding questions relating to the measurement and propagation of LF and IS and its encoding by the central nervous system relevant to possible perceptual and physiological effects. A range of possible research areas are identified.

Keywords
auditory transduction, infrasound, low-frequency sound, wind turbine noise

Date received: 18 April 2018; revised: 24 June 2018; accepted: 25 June 2018

Introduction

In recent years, there has been growing debate about the effects of wind turbine noise (WTN) on human health. A number of reviews have recently been published (e.g., Knopper et al., 2014; McCunney et al., 2014; Schmidt & Klokker, 2014; Van Kamp & Van Den Berg, 2017), some under the auspice of different government bodies in Australia (National Health and Medical Research Council, 2015), Canada (Council of Canadian Academies, 2015), and France (Lepoutre et al., 2017), with some appearing in the indexed scientific literature (most recently the Health Canada study; D. Michaud, 2015; D. S. Michaud et al., 2016a, 2016b; D. S. Michaud, Keith, et al., 2016). Many of these studies have adopted an epidemiological approach including various meta-analyses of the existing research reports concerning the health effects of WTN. By contrast, the popular press portrays a largely polarized picture where the discourse often appears less informed and more opinionated than scientifically based.

There are clearly complex factors surrounding complaints about WTs that, apart from the health and safety concerns, include financial and other material factors and potential interactions with individuals' perceptions of devices themselves, including their appearance and the sounds they make. These factors are all potential contributors to the annoyance produced by WTs. Many of these concerns—sometimes referred to as nocebo effects—have been recently reviewed in the literature (Chapman & Crichton, 2017; C. H. Hansen, Doolan, & Hansen, 2017). There seems, however, to have been little discussion (or systematic review) of potential perceptual and physiological effects of WTN at the level of the individual. This provides the principal motivation for this review. This review does not consider the important question of whether WTN affects human health, given the reviews and debates referred to earlier, but focuses on two important foundational issues. The first section reviews recent research examining the nature of the sound generated by WTs with a particular focus on the low-frequency sound (LF) and infrasound

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(IS), together with the mechanisms of its generation, propagation, and measures of human exposure. The objective of this first part is to understand the accuracy and usefulness of measures of this sound pressure at locations where people work and sleep. The second issue for focus concerns whether there are plausible mechanisms of transduction of LF/IS or evidence for somatic effects of LF/IS. This is an important question as a key link in any argument attempting to relate WTN exposure to ill health is the extent to which that sound can have a somatic influence. In closing, some of the existing peer-reviewed research examining the perceptual effects of exposure to LF and IS in the laboratory setting is reviewed.

This review has been confined largely to the scientific literature represented by the relevant peer-reviewed articles in indexed journals.

WTN, LF, and IS

There are a range of potential sound generators produced by WTs which include mechanical generators (gearboxes, electrical generators, cooling systems, etc., in the WT nacelle) as well as interactions between the moving blades and the air, particularly where there are variations in flow, angle of incidence, and pressure.

Sound produced by rotating blades on modern upwind WTs (where the rotor is on the front of the nacelle when viewed from the direction that the wind is coming) results in part from an interaction between the airflow disturbed by the rotating blade interacting with the supporting tower (e.g., Jung, Cheung, Cheong, & Shin, 2008; Sugimoto, Koyama, Kurihara, & Watanabe, 2008; reviewed in detail Van den Berg, 2006; Zajamšek, Hansen, Doolan, & Hansen, 2016). The sound generated by this mechanism is tonal in nature with a fundamental frequency at the blade passing frequency (BPF) and a series of six or so harmonics (Figure 1; for further details, see Schomer, Erdreich, Pamidighantam, & Boyle, 2015, their Figures 2 and 3). The fundamental frequency is dependent on the rate of rotation and number of blades and for a modern WT, the sound energy produced by this mechanism is generally well below 20 Hz.

Other sources of sound include the aerodynamic noise generated by air flow across and leaving the trailing edge of the blades (trailing edge noise) and mechanical noise from the nacelle equipment. By contrast with BPF noise, the aerodynamic noise from the blades is broadband with a low-pass roll-off (~5 dB per octave > 1 kHz; Figure 2; Oerlemans, Sijtsma, & López, 2007, their Figures 5, 9, and 11). The center frequency (500–750 Hz, A-weighted) is related to the size and power generation capacity of the turbine with a downward shift of around 1/3 octave comparing 2.3 to 3.6 MW turbines to <2 MW turbines accompanied by a relative increase in the proportion of energy at low frequencies for larger turbines (Moller & Pedersen, 2011).

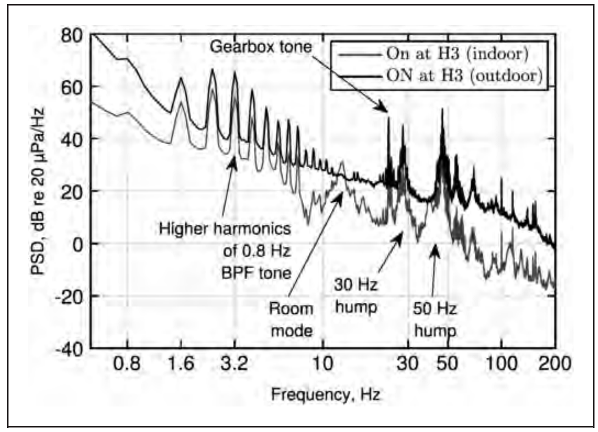

Figure 1. Comparison of indoor and outdoor spectral density recorded at an unoccupied dwelling approximately 3 km from a wind turbine. BPF = blade passing frequency; PSD = power spectral density.
Source: Reproduced with permission from Zajamsek et al. (2016), Figure 4.

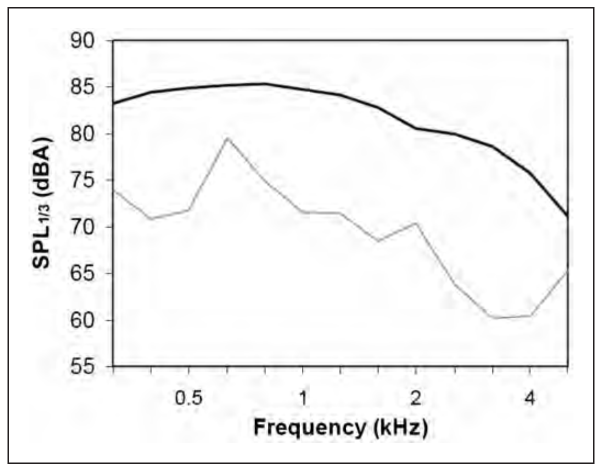

Figure 2. A-weighted average spectra of hub noise (thin line) and blade noise (thick line) recorded from a three-bladed pitch–controlled GAMESA G58 wind turbine (rotor diameter 58 m) using an acoustic array of 148 Panasonic WM-61 microphones 58 m upwind from the turbine.
Source: Reproduced with permission from Oerlemans et al. (2007).

In summary, from both a theoretical and an empirical standpoint, there is ample evidence demonstrating that a component of the sound energy produced by a WT is in the low and infrasonic frequency range. There are three other characteristics of LF that are relevant to understanding the measurements of sounds produced by WTs.

First, both modeling and measurement data have shown that the atmospheric boundary layer which extends from ground level to between 100 to thousands

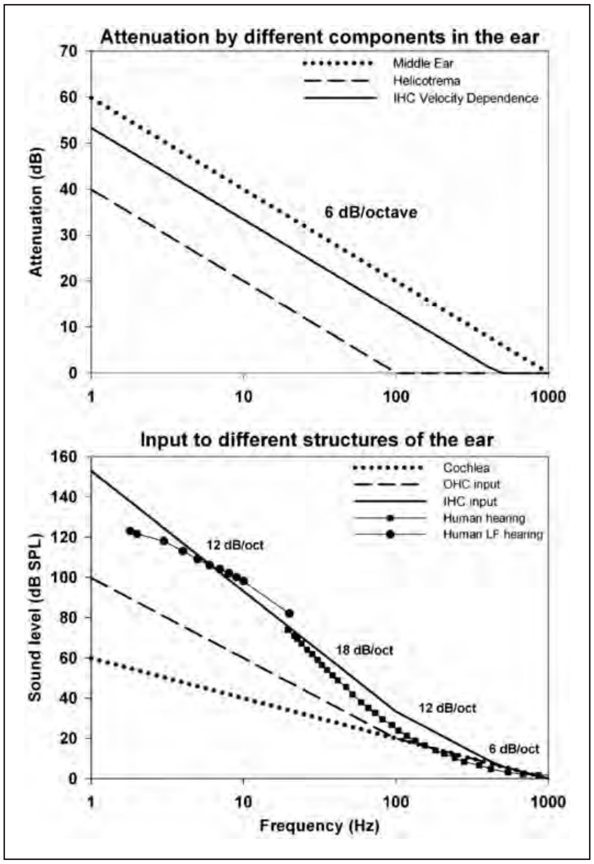

Figure 3. Upper panel: Estimated properties of high-pass filters associated with cochlear signal processing (based on Cheatham & Dallos, 2001). The curves show the low-frequency attenuation provided by the middle ear (6 dB/octave below 1000 Hz), the helicotrema (6 dB/octave below 100 Hz), and by the fluid coupling of the IHC resulting in the IHC dependence on stimulus velocity (6 dB/octave below 470 Hz). Lower panel: Combination of the three processes in the upper panel into threshold curves demonstrating: input to the cochlea (dotted) as a result of middle ear attenuation, input to the IHC as a result of additional filtering by the helicotrema, and input to the IHC as a result of their velocity dependence. Shown for comparison is the sensitivity of human hearing in the audible range (ISO226, 2003) and the sensitivity of humans to infrasound (Moller & Pedersen, 2004). The summed filter functions account for the steep (18 dB/octave) decrease in sensitivity below 100 Hz. OHC = outer hair cells; IHC = inner hair cells; LF = low-frequency sound.
Source: Reproduced with permission from Salt and Hullar (2010), Figure 3.

of meters can act as a low-frequency wave guide under a variety of common meteorological conditions (for review, see Marcillo, Arrowsmith, Blom, & Jones, 2015). With a stable boundary layer, which is common at night, LF radiation occurs as cylindrical waves and follows a two-dimensional decay model (−3 dB per doubling of distance) when measured downwind of a source (Zorumski & Willshire, 1989) in contrast to a three-dimensional decay model for higher frequency audible sound. Under such conditions, therefore, LF and IS levels decay more slowly with distance when compared with higher frequencies. Consistent with this, propagation of sound at the BPF from a 60-turbine wind farm has been recently measured using particularly sensitive equipment as far as 90 km from the source (Marcillo et al., 2015).

Second, IS and LF have wavelengths comparable with the dimensions of building structures such as homes which also allows for resonant interactions with those structures. Recent high-resolution data recorded inside and outside dwellings demonstrate such building cavity resonance in the 10 - to 20-Hz range (Pedersen, Møller, & Waye, 2007; Schomer et al., 2015; Zajamšek et al., 2016) along with other building resonances over a 2- to 80-Hz range. Third, sound attenuation provided by building walls is much less at low frequencies compared with higher frequency sounds (K. L. Hansen, Hansen, & Zajamšek, 2015; Thorsson et al., 2018) and very irregular because of the building resonances. These two observations indicate that exterior measures of LF and IS pressure are not necessarily good predictors of interior sound pressures as these are dependent on the particular characteristics of the structure.

Accurate measures of the sound pressure levels of LF and IS around WTs is complicated because of the very long wavelengths of sound at such low frequencies, and the high susceptibility of measurement microphones to atmospheric turbulence (i.e., wind noise). Special strategies such as very high performance wind-shields (Dauchez, Hayot, & Denis, 2016; K. Hansen, Zajamsek, & Hansen, 2014; Turnbull, Turner, & Walsh, 2012; Zajamšek et al., 2016) and the use of microphone arrays with sophisticated signal processing (Walker, 2013) are needed. There is a complex relationship between the wind speed and angle of incidence, atmospheric conditions, terrain, distance to the source and the number and distribution of sources, and the measurement of LF and IS (for an excellent review, see Van den Berg, 2006). External measures are complicated by wind noise and other interactions with the measuring instrument. The greater majority of measurements are external (rather than internal where the greatest disability is reported) and use A weighting which effectively filters out LF and IS frequencies. Even lower pass weightings (e.g., C weighting) exclude crucial low frequencies particularly at the BPF and first few harmonics. Measures made external to dwellings are not necessarily good predictors of dwelling interior pressures where people spend the majority of their time (particularly sleeping). In turn, internal measurements are also complicated, and often avoided by acousticians because of the influence of the room modes and occupational sources of noise, such as refrigerators and other household equipment. That there is a wide range of reported levels of LF and IS in and around wind farms should not be surprising, given the diversity of relevant factors (e.g., cf. Jung et al., 2008; Schomer et al., 2015; Sugimoto et al., 2008; Van den Berg, 2006). Given some of the physiological work reviewed later (particularly that relating to hydrops and basilar membrane biasing), use of a dosimetry approach to LF and IS exposure may prove a more appropriate measure for determining human exposure although this would require the development of new equipment and measurement techniques.

Sound Pressure Weighting Scales and WTN

The abovementioned considerations indicate that a complete understanding of sound energy emitted by WTs requires careful measurement and modeling approaches that are sensitive to the full range of possible sound frequencies. While the current practice of measuring and analyzing WTN using an A-weighted correction offers convenience and practicality, it will necessarily filter out much of the LF energy actually emitted by a WT. This approach appears to be motivated by practical measurement considerations and the assumption that, from the point of view of human perception, the auditory system sensitivity to sound level (loudness perception) is nonlinear and rolls off very sharply for frequencies below 1 kHz reaching −50 dB by 20 Hz (Keith et al., 2016; Yokoyama, Sakamoto, & Tachibana, 2014). These authors also argued that the A-weighted sound level of a wind farm is highly correlated with the sound levels of the LF and IS, and so A-weighted measures could act as a proxy for LF and IS levels. This supposition is, however, based on 1/3 octave C-weighted measures extending only to 16 Hz which is well above the BPF and it is not consistent with some recent data (e.g., Hansen, Walker, Zajamsek, & Hansen, 2015; Schomer et al., 2015). As reviewed earlier, there are also complicating factors relating to the potential difference in the propagation of IS and LF compared with the middle to high frequencies to which humans are sensitive. This suggests that, even if A-weighted measures are correlated with the total WT energy at a particular point in space, this may not provide an adequate indication of the relative sound levels at other distances from the source (see also Moller & Pedersen, 2011).

There is clearly a need for more research and development of methods to accurately measure and assess the level of exposure of individuals to LF and IS particularly in the built environment where individuals live and sleep. To be clear, in the first instance, this work needs to focus on the collection of high-quality scientific data to provide insights into the mechanisms and processes in play. While this may subsequently have implications for methods of making acoustic measurements in the field, the emphasis first needs to be on collecting high-quality scientific data to address the questions of sound propagation and human exposure.

Perceptual Sensitivity

Perceptual sensitivity to LF and IS has been studied for more than 80 years (reviewed in Moller & Pedersen, 2004), and although there is no international standard, the experimental data are in good agreement. Threshold rises sharply from 80 dB (SPL) at 20 Hz to around 124 dB SPL at 2 Hz and the perceptual effects also include vibration and the sensation of pressure at the ear drums. Consistent with these data, Yokoyama et al. (2014) showed that listeners were insensitive to resynthesized WTN in the laboratory at levels up to 56 dBA.

For a variety of biomechanical and other physiological reasons, the cochlea is known to be a highly nonlinear transducer. Given the relatively high sound levels required to achieve perceptual response to IS, the question arises as to whether this represents neural transduction at the fundamental frequency or sensitivity to nonlinear distortion products produced on the basilar membrane. While mechanisms of transduction are considered in more detail later, recent functional magnetic resonance imaging (fMRI) data (Dommes et al., 2009; Weichenberger et al., 2015) show auditory cortical activation to a 12-Hz tone at thresholds that are broadly consistent with those reviewed by Moller and Pederson (2004). This indicates that, regardless of whether IS is transduced as a fundamental or as a consequence of nonlinear distortion products, it does lead to activation of the auditory cortex providing a primary neural representation of these acoustic stimuli.

A more recent fMRI study (Weichenberger et al., 2017) took a different analytical approach using a regional homogeneity resting mode analysis and a relatively prolonged (200 s) 12-Hz stimulus. They report that subliminal sound levels (2 dB below measured threshold) also activated brain regions known to be involved in autonomic and emotional processing: In particular, the anterior cingulate cortex and amygdala—the latter is believed to be involved with stress and anxiety-related psychiatric disorders. The amygdala is also part of the nonleminiscal auditory pathway that mediates subcortical processing and has input to the reticular activating system, a key component regulating arousal and sleep (for discussion, see Weichenberger et al., 2017). This latter observation provides some explanation as to how subliminal IS stimulation could lead to arousal and potentially mediate sleep disturbances reported by some individuals.

Related to the question of individual differences, Moller and Pedersen (2004) make the observation that the dynamic range of the auditory system decreases significantly at low frequencies, demonstrated in the extreme compression of the equal loudness contours at 2 Hz (20–80 phon from 130 to 140 dB). This indicates that even small changes in pressure can result in very large changes in loudness perception. Likewise, small variations in threshold between individuals could produce significant differences in perceived loudness for the same pressure level stimulus. This would also result in differences in suprathreshold levels which, when taken in the context of the recent report of Weichenberger et al., could in turn explain some of the individual differences in reported physiological effects of WTN. A simple test of this prediction would be to measure the IS thresholds of individuals reporting physiological effects of exposure to WTN compared with those who report no effects under the same exposure conditions. If this proved to be discriminatory, then simple IS threshold measures would provide an indicator of likely susceptibility to WTN. Such measurements could involve perceptual impressions (Kuehler, Fedtke, & Hensel, 2015) or objective assessments such as fMRI (Weichenberger et al., 2017) or magnetoencephalogy (Bauer et al., 2013).

Physiological Transduction of LF and IS

Before considering the evidence for potential sensory or other transduction of LF and IS, it is useful to contextualize this discussion. As indicated in the Introduction section, a critical component in any argument attempting to link the sound level output from WTs (or any mechanical device) to ill health is the extent to which sound energy is able to influence the human body perceptually or somatically. If there is no influence, then it would be difficult to argue that reported health effects could be induced by sound or vibration. For instance, people in urban environments are exposed daily to significant qualities of low-level microwave radiation in the form of communications transmissions (radio, TV, cellular network, etc.) without any known effects of ill health (Valberg, Van Deventer, & Repacholi, 2007). This would likely be a consequence of the fact that, at these levels of exposure, microwave radiation is not an effective stimulus perceptually or somatically for the human body. By contrast, there is much debate and opinion as to whether the human nervous system is sensitive to the infrasonic and LF that is emitted by WTs. There are, unfortunately, very few peer-reviewed publications that consider the potential physiological mechanisms that might underlie sensory transduction of LF and IS. There is a much wider range of opinion pieces on the topic presented in a variety of formats (popular science magazines, newspaper articles, and self-published monographs and newsletters). Subsequently, we will consider principally reports or reviews in peer-reviewed scientific publications.

In a review in *Hearing Research*, Salt and Hullar (2010) outline a number of possible mechanisms by which the LF and IS could influence the function of the inner ear and lead to neural stimulation that may or may not be perceived as sound. These authors describe how, under normal physiological circumstances, the inner ear is remarkably insensitive to LF and IS. This results from the need to mechanically tune the sensory apparatus to sounds of greatest biological interest (in this case, from 100 Hz to a few kilohertz which is the range of human communication and of the inadvertent sounds of movement of predator or prey). Consequently, the anatomical structures of the cochlea would suffer significant damage in response to large mechanical displacements that would result from stimulation by even relatively low pressure LFs (for sounds of constant pressure, particle displacement is inversely proportional to frequency at +6 dB per octave).

There are three principal mechanisms providing this protective attenuation (see Figure 3; Salt & Hullar, 2010; for a very detailed review, see Dallos, 2012). First, the band-pass characteristics of the middle ear are roughly centered on 1 kHz and attenuate frequencies below that at 6 dB/octave. For a constant pressure, this inversely matches the increase in particle displacement so that for frequencies below 1 kHz, movement of the stapes and the amplitude of displacement input to the cochlea is constant. Second, low-frequency stimulation of the cochlea is reduced by the shunting of perilymph fluid between the chambers of the scala tympani and scala vestibuli through the helicotrema resulting in 6 dB/octave attenuation for frequencies less than 100 Hz. Third, the auditory transduction receptors, the inner hair cells (IHC) are sensitive to fluid velocity in the cochlea which results in a further attenuation of 6 dB octave below about 470 Hz. These three mechanisms add linearly to reduce stimulation of the IHC by 18 dB/octave between 100 Hz and 20 Hz.

Salt and Hullar (2010) make the important observation that as the outer hair cells (OHC) are sensitive to displacement (i.e., they are mechanically coupled and not fluid coupled to the tectorial membrane) which is constant for low frequencies, so even under physiologically normal conditions, at these low frequencies they should be stimulated at lower sound levels than the IHC. This prediction is borne out by the thresholds of endolymphatic potentials in the guinea pig cochlea to 5-Hz stimuli which represent strial current gated by OHC activity (Salt, Lichtenhan, Gill, & Hartsock, 2013). In contrast to the original estimates of OHC threshold (~40 dB lower than IHC at 5 Hz; Salt & Hullar, 2010), gain calculations in the later work suggest that the human apical cochlea could be similarly activated at around 55 dB to 65 dB SPL (corresponding to −38 to −28 dBA). This surprisingly high level of sensitivity of

OHCs to LF (when compared with IHC activation and perceptual threshold) is strongly supported by recent work examining the spontaneous otoacoustic emissions in humans (Drexl, Krause, Gürkov, & Wiegrebe, 2016; see also Drexl, Otto, et al., 2016; Jeanson, Wiegrebe, Gürkov, Krause, & Drexl, 2017; Kugler et al., 2014). It has been known for quite some time using human distortion product otoacoustic emissions (e.g., Hensel, Scholz, Hurttig, Mrowinski, & Janssen, 2007) as well as in vivo animal data (Patuzzi, Sellick, & Johnstone, 1984) that LF and IS do affect cochlear processing and that the cochlea aqueduct does pass IS frequencies into the inner ear (Traboulsi & Avan, 2007). The perceptual and other downstream consequences, however, are still not well studied. The more recent focus on the modulation of OHC activity is likely to provide important insights as to the physiological effects of IS and LF on cochlear processing. While the sensory role of OHCs are currently not well understood, they do carry sensory information via Type-II afferent fibers into the brain and probably play a role in signaling the off-set bias (and therefore operating point) of the basilar membrane and therefore also affect IHC transduction.

Before considering the effects of possible dysfunction of this system, it is worth summarizing the implications mentioned earlier. The healthy human ear significantly attenuates low-frequency input to the IHCs below around 100 Hz ($\sim$18 dB/octave). It is likely that at very low frequencies (<20 Hz), the OHCs are responding to stimuli at levels well below those producing activation of the IHCs. It is acoustic stimulation of the IHC which is the effective perceptual stimulus for hearing. Nonetheless, OHCs also have a sensory (afferent) input to the brain, although their stimulation is unlikely to lead to auditory perception per se. What is critical to emphasize at this juncture is that although the mechanisms outlined by Salt and Hullar (2010) are plausible and based on a large body of well-founded research, they do not by themselves constitute a demonstration of direct transduction of LF and IS by the inner ear. The effects of LF on OHC activity, however, could modulate transduction by the IHC, and such affects would likely be perceptible.

These data do provide, however, a strong prima facia case for neural transduction of LF and IS that needs to be properly examined at a functional and perceptual level in both animal and human models. Some critics of Salt and Hullar (2010) have argued that the level of LF and IS required to stimulate the OHCs is much greater than that recorded near wind farms. Given, however, the range of technical issues in making such acoustic measurements and the diversity of reported levels reviewed earlier, this claim is similarly limited by the available acoustic data. Furthermore, the recent work examining the guinea pig endocochlear potential (Salt et al., 2013) and human otoacoustic emissions (e.g., Drexl, Otto, et al., 2016; Kugler et al., 2014) indicate even greater levels of sensitivity of OHCs to LF when compared with the perceptual threshold mediated by IHC activity than first predicted. This suggests the need for a review of such conclusions.

Salt and Hullar (2010) also review the consequences of some pathologic conditions of the inner ear in terms of the potential to increase sensitivity to LF and IS. For instance, blockage or increased resistance of the helicotrema by a condition such as endolymphatic hydrops will reduce fluid shunting and reduce the attenuation for frequencies <100 Hz by up to 6 dB. Acute endolymphatic hydrops can be induced by exposure to low frequencies, although the relationship is complex and suggests that a dosimetry approach to exposure could be most informative. Hydrops would also lead to changes in the operating point of the basilar membrane resulting in a variety of changes in IHC sensory transduction including increased distortion. A further mechanism considered by Salt and Hullar is the increased fluid coupling of vestibular cells to sound input produced by changes in the input impedance of the vestibular system in conditions such as superior canal dehiscence (SCD), which can result in sound induced dizziness or vertigo, nausea, and nystagmus (Tullio phenomena).

Schomer et al. (2015) also examine potential physiological mechanisms that could mediate effects of LF and IS. They draw a link between the nauseogenic effects of low-frequency vestibular stimulation in seasickness and the potential vestibular stimulation by IS under normal listening conditions (as opposed to pathologic conditions of SCD). Using data collected by the U.S. Navy on nauseogenic effectiveness of low-frequency vestibular stimulation produced by whole body motion, they found significant overlap between the most effective nauseogenic frequencies and BPF of modern and larger WTs. Using a first-order model, they also demonstrate a better than order of magnitude equivalence between the force applied to the otoconia in the vestibular apparatus produced by whole body motion of 0.7 Hz at 5 m/s^2 peak and by IS of 0.7 Hz at 54 dB (SPL). Building on previous anatomical work (Uzun-Coruhlu, Curthoys, & Jones, 2007), Schomer et al. argue that pressure normal to the surface of the macular in the inner ear will provide an effective stimulus to the vestibular hair cells in the same way as the sheer motion between the otoconial membrane produced during linear acceleration of the head. While a plausible explanation, it is important to recognize that this suggestion is highly speculative and no data have yet been provided to support this latter assertion. Leventhall (2015) has also questioned this model although not in a peer-reviewed forum. Of note, however, the comparison with seasickness does add to the argument that a dosimetric approach to exposure may be more appropriate than measures of peak or root-mean-square sound pressure.

Perceptual Effects of Laboratory Exposure to LF and IS

A number of laboratory studies have directly exposed human listeners to IS and LF (e.g., Crichton, Dodd, Schmid, Gamble, & Petrie, 2014; Tonin, Brett, & Colagiuri, 2016) either directly recorded from WT (e.g., Yokoyama et al., 2014) or synthesized to reproduce key elements of these recordings (e.g., Tonin et al., 2016). A range of exposure symptoms have been reported but no systematic or significant effects of IS and LF have been demonstrated.

In general, sample sizes have been relatively small (e.g., $n = 2$, Hansen, Walker, et al., 2015; $n = 72$, Tonin et al., 2016) with studies likely to be statistically under powered (see Supplementary Material). Exposure times have been in the order of minutes to a few 10 s of minutes with a diversity of presentation levels above and below the IS/LF levels reported in the field.

Some free field stimulus playback systems have failed to deliver sound at the BPF and low-order harmonics frequencies (Yokoyama et al., 2014) while others have used headphone playback (Tonin et al., 2016). Many studies have not been blinded or double blinded, while others have been specifically designed to examine the effects of demand characteristics by manipulating expectancy (e.g., Crichton et al., 2014; Tonin et al., 2016). The latter studies have demonstrated, unsurprisingly, that manipulation of expectancy regarding the physiological effects of WT IS and LF has a moderate effect on the number and strength of symptoms reported by subjects regardless of the noise exposure conditions. Interestingly, Tonin et al. (2016) also report in their double-blind study that the presence of IS increased concern about health effects of WTN-expressed postexposure although subjects reported not hearing the IS stimulus.

In summary, there appears a prima facia case for the existence of sensory transduction of LF and IS and its representation in the nervous system. While a number of plausible mechanisms have been proposed, the actual mechanism of transduction has yet to be demonstrated. There are some laboratory-based studies examining the exposure to either recorded or simulated WTN, but the current data regarding potential perceptual or physiological are inconclusive.

General Summary and Conclusions

Although not an exhaustive survey of this literature, this review indicates that there are questions relating to the measurement and propagation of LF and IS and its encoding by the central nervous system (e.g., Dommes et al., 2009; Weichenberger et al., 2017) that are relevant to the possible perceptual and physiological effects of WTN but for which we do not have a good scientific understanding. There is much contention and opinion in these areas that, from a scientific perspective, are not well founded in the data, simply because there are little data available that effectively address these issues. This justifies a clear call to action for resources and support to promote high-quality scientific research in these areas.

Some of the research questions that arise from this review include the need for the following:

1. A more complete characterization and modeling of the sound generated by individual WTs and the large aggregations that comprise the modern windfarm. Such research needs to consider the spectrum from the BPF to its higher harmonics and incorporate the different propagation models that apply to different frequency ranges along with the effects of terrain, atmospheric conditions, and other potential modifiers of the sound.
2. The development of a more complete understanding of the interactions between WTN and the built structures in which people live and sleep. Such research needs to consider the different modes of excitation including substrate vibration, cavity resonances (including Helmholtz resonance and the interconnection of rooms), and differential building material sound insulation. New methods need to be developed for accurately and effectively measuring acute and chronic exposure (dosimetry) and for managing wind and other interference in the measurements.
3. Structural and aeronautic engineering research to discover ways to minimize the BPF generation and other potentially annoying sound sources.
4. Research to directly examine the effects of IS on the cochlea and vestibular apparatus. Although different theories have been advanced as to how IS and LF might be transduced and excite the central nervous system, there are little direct data demonstrating whether and how this occurs.
5. Research to better understand the neural connectivity of the putative transducers in the inner ear and an understanding of the consequences of their possible activation by IS and LF, notwithstanding the recent brain imaging data demonstrating differential activation of different brain structures (including the auditory cortex) by IS.
6. Research to better characterize the physiology of individuals who report susceptibility to WTN with a focus on whether these individuals represent a statistical tail of a normally distributed population or display other dysfunction or pathology that mediates susceptibility (e.g., SCD or lymphatic hydrops). In particular, an examination is required of the

hypothesis that small individual differences in threshold sensitivity to IS could underlie the differential activation of the anterior cingulate cortex and amygdala at subliminal sound levels.

This is not intended to be an exhaustive list of possible research areas. A research initiative to encourage and develop a very wide diversity of proposals is warranted as it is from the depth, capacity, and ingenuity of the researchers that work in these areas that the insights and the most effective research questions will come.

Acknowledgments

The authors would like to acknowledge the help of Dr. Christophe Micheyl in developing the statistical model in the supplementary material.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The authors thank the Secretariat at the Australian Government Department of the Environment and Energy for their support for the Independent Scientific Committee on Wind Turbines.

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EXHIBIT
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Bulletin of Science, Technology & Society
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Bulletin of Science Technology & Society 2011 31: 296
DOI: 10.1177/0270467611412555

The online version of this article can be found at:
http://bst.sagepub.com/content/31/4/296

Published by:
SAGE
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On behalf of:
National Association for Science, Technology & Society

Bulletin of Science, Technology & Society
31(4) 296–302

DOI: 10.1177/0270467611412555
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Infrasound From Wind Turbines Could Affect Humans

Alec N. Salt[1] and James A. Kaltenbach[2]

Abstract

Wind turbines generate low-frequency sounds that affect the ear. The ear is superficially similar to a microphone, converting mechanical sound waves into electrical signals, but does this by complex physiologic processes. Serious misconceptions about low-frequency sound and the ear have resulted from a failure to consider in detail how the ear works. Although the cells that provide hearing are insensitive to infrasound, other sensory cells in the ear are much more sensitive, which can be demonstrated by electrical recordings. Responses to infrasound reach the brain through pathways that do not involve conscious hearing but instead may produce sensations of fullness, pressure or tinnitus, or have no sensation. Activation of subconscious pathways by infrasound could disturb sleep. Based on our current knowledge of how the ear works, it is quite possible that low-frequency sounds at the levels generated by wind turbines could affect those living nearby.

Keywords

cochlea, hair cells, A-weighting, wind turbine, Type II auditory afferent fibers

Wind Turbines Generate Infrasound

The sounds generated by wind turbines vary widely, depending on many factors such as the design, size, rotor speed, generator loading, and different environmental conditions such as wind speed and turbulence (e.g., Jakobsen, 2005). Under some conditions, such as with a low wind speed and low generator loading, the sounds generated appear to be benign and are difficult to detect above other environmental sounds (Sonus, 2010).

But in many situations, the sound can contain a substantial low-frequency infrasound component. One study (Van den Berg, 2006) reported wind turbine sounds measured in front of a home 750 m from the nearest turbine of the Rhede wind farm consisting of Enercon E-66 1.8 MW turbines, 98 m hub height, and 35 m blade length. A second study (Jung & Cheung, 2008) reported sounds measured 148 to 296 m from a 1.5 MW turbine, 62 m hub height, 36 m blade length. In both these studies, which are among the few publications that report full-spectrum sound measurements of wind turbines, the sound spectrum was dominated by frequencies below 10 Hz, with levels of over 90 dB SPL near 1 Hz.

The infrasound component of wind turbine noise is demonstrated in recordings of the sound in a home with GE 1.5 MW wind turbines 1,500 ft downwind as shown in Figure 1. This 20-second recording was made with a microphone capable of recording low-frequency components. The sound level over the recording period, from which this excerpt was taken, varied from 28 to 43 dBA. The audible and inaudible (infrasound) components of the sound are demonstrated by filtering the waveform above 20 Hz (left) or below 20 Hz (right). In the audible, high-pass filtered waveform, the periodic "swoosh" of the blade is apparent to a varying degree with time. It is apparent from the low-pass filtered waveform that the largest peaks in the original recording represent inaudible infrasound. Even though the amplitude of the infrasound waveform is substantially larger than that of the audible component, this waveform is inaudible when played by a computer's sound system. This is because conventional speakers are not capable of generating such low frequencies and even if they could, those frequencies are typically inaudible to all but the most sensitive unless played at very high levels. It was also notable in the recordings that the periods of high infrasound level do not coincide with those times when the audible component is high.

This shows that it is impossible to judge the level of infrasound present based on the audible component of the sound. Just because the audible component is loud does not mean that high levels of infrasound are present. These measurements show that wind turbine sounds recorded inside a home can contain a prominent infrasound component.

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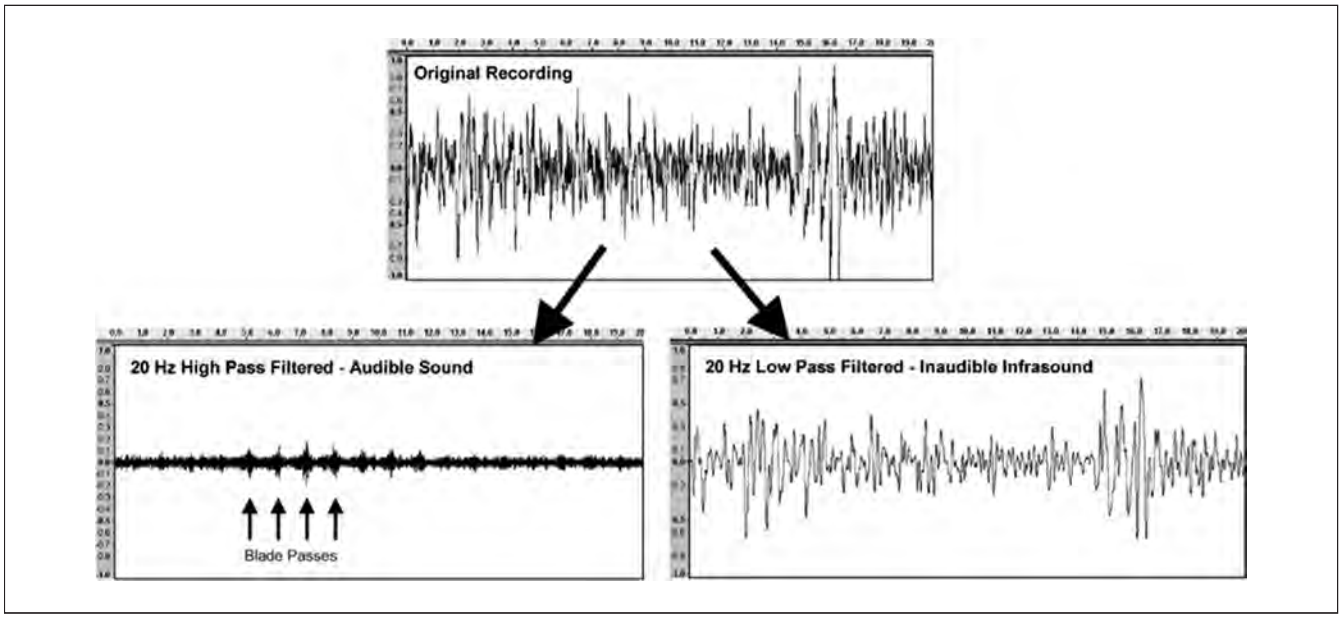

Figure 1. *Upper Panel:* Full-spectrum recording of sound from a wind turbine recorded for 20 seconds in a home with the wind turbine 1,500 ft downwind (digital recording kindly provided by Richard James). *Lower Left Panel:* Result of high-pass filtering the waveform at 20 Hz, showing the sound that is heard, including the sounds of blade passes. *Lower Right Panel:* Result of low-pass filtering the waveform at 20 Hz, showing the infrasound component of the sound

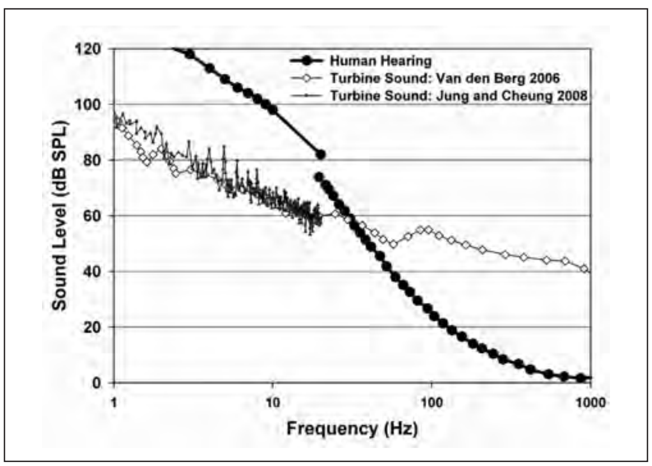

Figure 2. Wide band spectra of wind turbine sounds (Jung & Cheung, 2008; Van den Berg, 2006) compared with the sensitivity of human hearing (International Organization for Standardization, 2003, above 20 Hz; Møller & Pederson, 2004, below 20 Hz). The levels of sounds above 30 Hz are above the audibility curve and would be heard. Below 30 Hz, levels are below the audibility curve so these components would not be heard

Wind Turbine Infrasound Is Typically Inaudible

Hearing is very insensitive to low-frequency sounds, including those generated by wind turbines. Figure 2 shows examples of wind turbine sound spectra compared with the sensitivity of human hearing. In this example, the turbine sound components above approximately 30 Hz are above threshold and therefore audible. The sounds below 30 Hz, even though they are of higher level, are below the threshold of audibility and therefore may not be heard. Based on this comparison, for years it has been assumed that the infrasound from wind turbines is not significant to humans. Leventhall (2006) concluded that "infrasound from wind turbines is below the audible threshold and of no consequence." (p.34) Leventhall (2007) further stated that "if you cannot hear a sound you cannot perceive it in other ways and it does not affect you." (p.135)

Renewable UK (2011), the website of the British Wind Energy Association, quotes Dr. Leventhall as stating, "I can state quite categorically that there is no significant infrasound from current designs of wind turbines." Thus, the fact that hearing is insensitive to infrasound is used to exclude the possibility that the infrasound can have any influence on humans. This has been known for many years in the form of the statement, "What you can't hear can't affect you." The problem with this concept is that the sensitivity of "hearing" is assumed to equate with sensitivity of "the ear." So if you cannot hear a sound then it is assumed that the sound is insufficient to stimulate the ear. Our present knowledge of the physiology of the ear suggests that this logic is incorrect.

The Ear Is Sensitive to Wind Turbine Infrasound

The sensory cells responsible for hearing are contained in a structure in the cochlea (the auditory portion of the inner ear) called the organ of Corti. This organ runs the entire length of the cochlear spiral and contains two types of sensory cells, which have completely different properties. There is one row

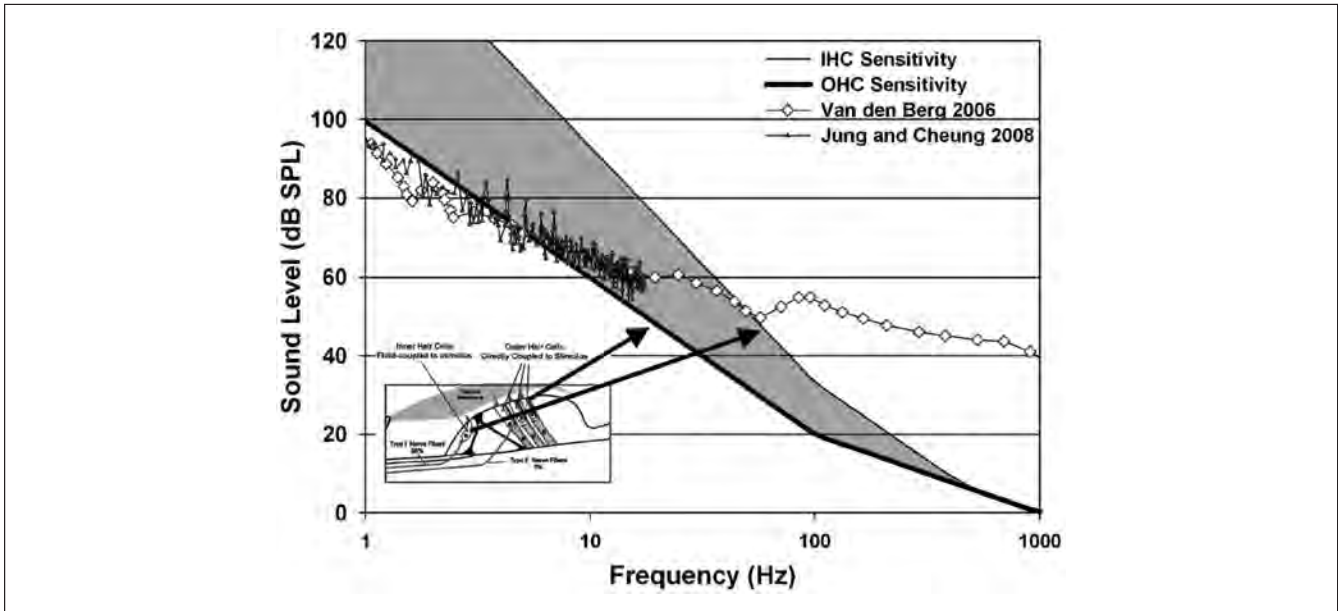

Figure 3. The thin line shows the estimated sensitivity of inner hair cells (IHC) as a function of frequency, which is comparable with the human audibility curve shown in Figure 2 and which is consistent with hearing being mediated by the IHC (based on Cheatham & Dallos, 2001). The thick line shows the estimated sensitivity of the outer hair cells (OHC), which are substantially more sensitive than the IHC. Sound components of the overlaid wind turbine spectra within the shaded region (approximately 5 to 50 Hz) are too low to stimulate the IHC and cannot therefore be heard but are of sufficient level to stimulate the OHC. The inset shows a cross section of the sensory organ of the cochlea (the organ of Corti) showing the locations of the IHC and OHC

of sensory inner hair cells (IHC) and three rows of outer hair cells (OHC) as shown schematically in the inset to Figure 3. For both IHC and OHC, sound-induced deflections of the cell's sensory hairs provide stimulation and elicit electrical responses. Each IHC is innervated by multiple nerve fibers that transmit information to the brain, and it is widely accepted that hearing occurs through the IHC. The rapidly declining sensitivity of hearing at lower frequencies (Figure 2) is accounted for by three processes that selectively reduce low-frequency sensitivity (Cheatham & Dallos, 2001), specifically the properties of middle ear mechanics, from pressure shunting through the cochlear helicotrema and from "fluid coupling" of the inner hair cell stereocilia to the stimulus (reviewed in detail by Salt & Hullar, 2010).

The combined effect of these processes, quantified by Cheatham and Dallos (2001), are shown as the "IHC sensitivity" curve in Figure 3. The last component attenuating low frequencies, the so-called fluid coupling of input, arises because the sensory hairs of the IHC do not contact the overlying gelatinous tectorial membrane but are located in the fluid space below the membrane.

As a result, measurements from the IHC show that they do not respond to sound-induced displacements of the structure but instead their amplitude and phase characteristics are consistent with them responding to the velocity of the stimulus. As stimulus frequency is lowered, the longer cycles result in lower stimulus velocity, so the effective stimulus falls by 6 dB/octave. This accounts for the known insensitivity of the IHC to low-frequency stimuli. For low frequencies, the calculated sensitivity of IHC (Figure 3) compares well with measures of hearing sensitivity (Figure 2), supporting the view that hearing is mediated by the IHC.

The problem, however, arises from the more numerous OHC of the sensory organ of Corti of the ear. Anatomic studies show that the sensory hairs of the OHC are embedded in the overlying tectorial membrane, and electrical measurements from these cells show their responses depend on the displacement rather than the velocity of the structure. As a result, their responses do not decline to the same degree as IHC as frequency is lowered.

Their calculated sensitivity is shown as the "OHC sensitivity" curve in Figure 3. It is important to note that the difference between IHC and OHC responses has nothing to do with frequency-dependent effects of the middle ear or of the helicotrema (the other two of the three components mentioned above). For example, any attenuation of low-frequency stimuli provided by the helicotrema will equally affect both the IHC and the OHC. So the difference in sensitivity shown in Figure 3 arises purely from the difference in how the sensory hairs of the IHC and OHC are coupled to the overlying tectorial membrane.

The important consequence of this physiological difference between the IHC and the OHC is that the OHC are stimulated at much lower levels than the IHC. In Figure 3, the portion of the wind turbine sound spectrum within the shaded region represents frequencies and levels that are too low to be heard, but which are sufficient to stimulate the OHC of the ear.

This is not confined to infrasonic frequencies (below 20 Hz), but in this example includes sounds over the range from 5 to 50 Hz. It is apparent that the concept that "sounds you can't hear cannot affect you" cannot be correct because it does not recognize these well-documented physiologic properties of the sensory cells of the inner ear.

Stimulation of OHC at inaudible, low levels can have potentially numerous consequences. In animals, cochlear microphonics demonstrating the responses of the OHC can be recorded to infrasonic frequencies (5 Hz) at levels as low as 40 dB SPL (Salt & Lichtenhan, in press). The OHCs are innervated by Type II nerve fibers that constitute 5% to 10% of the auditory nerve fibers, which connect the hair cells to the brainstem. The other 90% to 95% come from the IHCs. Both Type I (from IHC) and Type II (from OHC) nerve fibers terminate in the cochlear nucleus of the brainstem, but the anatomical connections of the two systems increasingly appear to be quite different. Type I fibers terminate on the main output neurons of the cochlear nucleus. For example, in the dorsal part of the cochlear nucleus, Type I fibers connect with fusiform cells, which directly process information received from the ear and then deliver it to higher levels of the auditory pathway. In contrast, Type II fibers terminate in the granule cell regions of the cochlear nucleus (Brown, Berglund, Kiang, & Ryugo, 1988). Some granule cells receive direct input from Type II fibers (Berglund & Brown, 1994). This is potentially significant because the granule cells provide a major source of input to nearby cells, whose function is inhibitory to the fusiform cells that are processing heard sounds. If Type II fibers excite granule cells, their ultimate effect would be to diminish responses of fusiform cells to sound. Evidence is mounting that loss of or even just overstimulation of OHCs may lead to major disturbances in the balance of excitatory and inhibitory influences in the dorsal cochlear nucleus. One product of this disturbance is the emergence of hyperactivity, which is widely believed to contribute to the perception of phantom sounds or tinnitus (Kaltenbach et al., 2002; Kaltenbach & Godfrey, 2008). The granule cell system also connects to numerous auditory and nonauditory centers of the brain (Shore, 2005). Some of these centers are directly involved in audition, but others serve functions as diverse as attentional control, arousal, startle, the sense of balance, and the monitoring of head and ear position (Godfrey et al., 1997).

Functions that have been attributed to the dorsal cochlear nucleus thus include sound localization, cancellation of self-generated noise, orienting the head and ears to sound sources, and attentional gating (Kaltenbach, 2006; Oertel & Young, 2004). Thus, any input from OHCs to the circuitry of the dorsal cochlear nucleus could influence functions at several levels.

A-Weighted Wind Turbine Sound Measurements

Measurements of sound levels generated by wind turbines presented by the wind industry are almost exclusively A-weighted and expressed as dBA. When measured in this manner, the sound levels near turbines are typically in the range of 30 to 50 dBA, making wind turbine sounds,

> about the same level as noise from a flowing stream about 50-100 meters away or the noise of leaves rustling in a gentle breeze. This is similar to the sound level inside a typical living room with a gas fire switched on, or the reading room of a library or in an unoccupied, quiet, air-conditioned office. (Renewable UK, 2011)

On the basis of such measurements, we would expect wind turbines to be very quiet machines that would be unlikely to disturb anyone to a significant degree. In contrast, the human perception of wind turbine noise is considerably different. Pedersen and Persson-Waye (2004) reported that for many other types of noise (road traffic, aircraft, railway), the level required to cause annoyance in 30% of people was over 70 dBA, whereas wind turbine noise caused annoyance of 30% of people at a far lower level, at around 40 dBA. This major discrepancy is probably a consequence of A-weighting the wind turbine sound measurements, thereby excluding the low-frequency components that contribute to annoyance. A-weighting corrects sound measurements according to human hearing sensitivity (based on the 40 phon sensitivity curve). The result is that low-frequency sound components are dramatically deemphasized in the measurement, based on the rationale that these components are less easily heard by humans. An example showing the effect of A-weighting the turbine sound spectrum data of Van den Berg (2006) is shown in Figure 4. The low-frequency components of the original spectrum, which resulted in a peak level of 93 dB SPL at 1 Hz, are removed by A-weighting, leaving a spectrum with a peak level of 42 dBA near 1 kHz. A-weighting is perfectly acceptable if hearing the sound is the important factor. A problem arises though when A-weighted measurements or spectra are used to assess whether the wind turbine sound affects the ear. We have shown above that some components of the inner ear, specifically the OHC, are far more sensitive to low-frequency sounds than is hearing. Therefore, A-weighted sounds do not give a valid representation of whether wind turbine noise affects the ear or other aspects of human physiology mediated by the OHC and unrelated to hearing. From Figure 3, we know that sound frequencies down to 3 to 4 Hz may be stimulating the OHC, yet the A-weighted spectrum in Figure 4 cuts off all components below approximately 14 Hz. For this reason, the determination of whether wind turbine sounds affect people simply cannot be made based on A-weighted sound measurements. A-weighted measurements are inappropriate for this purpose and give a misleading representation of whether the sound affects the ear.

Alternatives to A-weighting are the use of full-spectrum (unweighted), C-weighted, or G-weighted measurements. G-weighted measurements use a weighting curve based on the human audibility curve below 20 Hz and a steep cutoff above 20 Hz so that the normal audible range of frequencies is deemphasized. Although the shape of this function is arbitrary

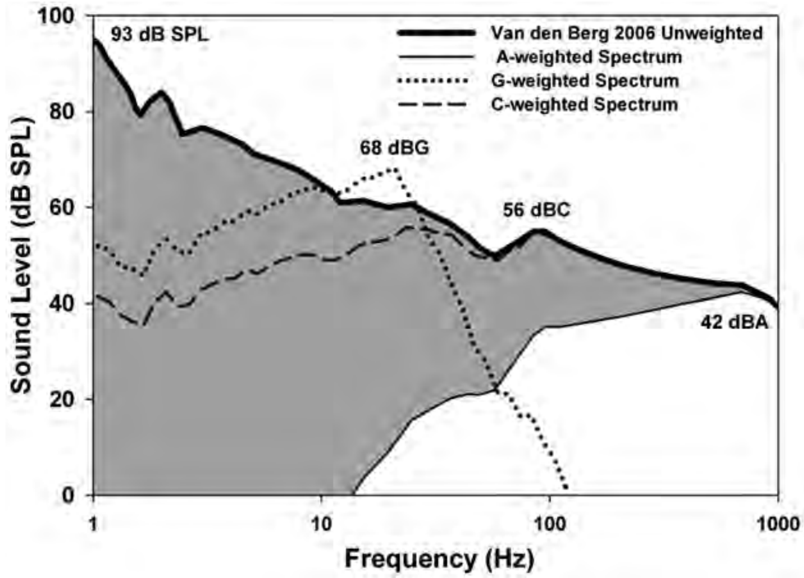

Figure 4. Low-frequency components of wind turbine sound spectrum (below 1 kHz) before and after A-weighting. The original spectrum was taken from Van den Berg (2006). The shaded area represents the degree of alteration of the spectrum by A-weighting. A weighting (i.e., adjusting the spectrum according to the sensitivity of human hearing) has the effect of ignoring the fact that low-frequency sounds can stimulate the OHC at levels that are not heard. Representing this sound as 42 dBA, based on the peak of the spectrum, ignores the possibility that low-frequency components down to frequencies as low as 5 Hz (from Figure 3) are stimulating the OHC. Also shown are the spectra after G-weighting (dotted) and C-weighting (dashed) for comparison

when hearing is not the primary issue, it does give a measure of the infrasound content of the sound that is independent of higher frequency, audible components, as shown in Figure 4. By applying the function to the normal human hearing sensitivity curve, it can be shown that sounds of approximately 95 dBG will be heard by humans, which agrees with observations by Van den Berg (2006). Similarly, by G-weighting the OHC sensitivity function in Figure 3, it can be estimated that sound levels of 60 dBG will stimulate the OHC of the human ear. In a survey of infrasound levels produced by wind turbines measured in dBG (Jakobsen, 2005), upwind turbines typically generated infrasound of 60 to 70 dBG, although levels above and below this range were observed in this and other studies. From Jakobsen's G-weighted measurements, we conclude that the level of infrasound produced by wind turbines is of too low a level to be heard, but in most cases is sufficient to cause stimulation of the OHC of the human ear. C-weighting also provides more representation of low-frequency sound components but still arbitrarily de-emphasizes infrasound components.

Is the Infrasound From Wind Turbines Harmful to Humans Living Nearby?

Our present understanding of inner ear physiology and of the nature of wind turbine sounds demonstrates that low-level infrasound produced by wind turbines is transduced by the OHC of the ear and this information is transmitted to the cochlear nucleus of the brain via Type II afferent fibers. We therefore conclude that dismissive statements such as "there is no significant infrasound from current designs of wind turbines" are undoubtedly false. The fact that infrasound-dependent information, at levels that are not consciously heard, is present at the level of the brainstem provides a scientific basis for the possibility that such sounds can have influence on people. The possibility that low-frequency components of the sound could contribute both to high annoyance levels and possibly to other problems that people report as a result of exposure to wind turbine noise cannot therefore be dismissed out of hand.

Nevertheless, the issue of whether wind turbine sounds can cause harm is more complex. In contrast to other sounds, such as loud sounds, which are harmful and damage the internal structure of the inner ear, there is no evidence that low-level infrasound causes this type of direct damage to the ear. So infrasound from wind turbines is unlikely to be harmful in the same way as high-level audible sounds.

The critical issue is that if the sound is detected, then can it have other detrimental effects on a person to a degree that constitutes harm? A major complicating factor in considering this issue is the typical exposure duration. Individuals living near wind turbines may be exposed to the turbine's sounds for prolonged periods, 24 hours a day, 7 days a week for weeks, possibly extending to years, although the sound level will vary over time with varying wind conditions. Although there have been many studies of infrasound on humans, these have typically involved higher levels for limited periods (typically of up to 24 hours). In a search of the literature, no studies were found that have come close to replicating the long-term exposures to low-level infrasound experienced by those living near wind turbines. So, to date, there are no published studies showing that such prolonged exposures do not harm humans. On the other hand, there are now numerous reports (e.g., Pierpont, 2009; Punch, James, & Pabst, 2010), discussed extensively in this journal, that are highly suggestive that individuals living near wind turbines are made ill, with a plethora of symptoms that commonly include chronic sleep disturbance. The fact that such reports are being dismissed on the grounds that the level of infrasound produced by wind turbines is at too low a level to be heard appears to totally ignore the known physiology of the ear. Pathways from the OHC to the brain exist by which infrasound that cannot be heard could influence function. So, in contrast, from our perspective, there is ample evidence to support the view that infrasound could affect people, and which justifies the need for more detailed scientific studies of the problem. Thus, it is possible that people's health could suffer when turbines are placed too close to their homes and this becomes more probable if sleep is disturbed by the infrasound. Understanding these phenomena may be important to deal with other sources of low-frequency noise and may establish why some individuals are more sensitive than others. A better understanding may also allow effective procedures to be implemented to mitigate the problem.

We can conclude that based on well-documented knowledge of the physiology of the ear and its connections to the brain, it is scientifically possible that infrasound from wind turbines could affect people living nearby.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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EXHIBIT

21

WIND TURBINES AND GHOST STORIES: THE EFFECTS OF INFRASOUND ON THE HUMAN AUDITORY SYSTEM

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Introduction

Climate change and fossil fuel depletion have pushed many countries to seek and invest in alternative clean energy sources, such as wind energy. By converting kinetic energy from the wind into mechanical or electrical energy, wind farms in California, for example, power nearly 850,000 households each year, while producing negligible green house gases and contributing little to water pollution[1] (see Fig. 1). Nevertheless, several ecological and environmental concerns remain. High levels of infrasound and low frequency sounds generated by wind turbines pose a potentially serious threat to communities near wind farms. Wind energy companies remain largely dismissive, claiming that wind turbine noise is subaudible, undetectable by humans, and therefore presents minimal risk to human health. However, various cochlear microphonic, distortion product otoacoustic emission, and functional magnetic resonance imaging (fMRI) studies have demonstrated the detection of infrasound by the human inner ear and auditory cortex. Additional psychosomatic stress and disorders, including the "wind turbine syndrome" and paranormal experiences, are also linked to infrasound exposures.[2,3] With wind turbines generating substantial levels of infrasound and low frequency sound, modifications and regulations to wind farm engineering plans and geographical placements are necessary to minimize community exposure and potential human health risks.

"...studies provide strong evidence for infrasound impact on human peripheral and central auditory responses."

Infrasound definition

It is popular belief that the audio frequency range of human hearing is from 20 to 20,000 Hz and that anything beyond these limits is undetectable by humans. Infrasound is the term that describes the "inaudible" frequencies below 20 Hz. Such a belief is based on the steep slope of hearing thresholds toward the lower end of the human hearing range.[4,5] At 1 kHz, the sound pressure level (SPL) necessary to perceive a 10 phon sound is 10 dB SPL. At 20 Hz, the minimum SPL for 10 phon sound perception has increased to about 84 dB SPL. The phon is a unit that describes perceived loudness level. With decreasing frequencies, the SPLs necessary for sound perception increase rapidly, making very low frequencies at a normally audible intensity more difficult to detect than higher frequencies of the same intensity. Humans' lack of sensitivity to low frequencies is also reflected in the compression of hearing thresholds. At 1 kHz, the SPLs capable of triggering hearing range from 4 to more than 100 dB SPL, exceeding 100 dB in span and increasing at 10 dB/phon. In contrast, the SPL range at 20 Hz is from approximately 80 to 130 dB SPL, spanning only about 50 dB and increasing at 5 dB/phon.[4] In other words, a relatively small increase in SPL at 20 Hz would

Fig. 1. San Gorgonio Pass Windfarm in Riverside County, California. With more than 2,000 wind turbines installed, this windfarm produces enough electricity to power Palm Springs and the entire Coachella Valley.[28] Photograph by Annie Chen

change the perception of this tone from barely audible to very loud. On the other hand, perceivable changes in loudness level at 1 kHz would require larger changes in SPL. The combination of SPL threshold increase and range compression results in poor intensity discrimination at low-frequencies in most people.

However, this audio frequency range is misleading and variable, as inter-individual differences in hearing sensitivity allow some people to detect the "inaudible." Human hearing thresholds have been reported for frequencies from slightly below 20 Hz to as low as 2 Hz in some cases.[6,7] Furthermore, humans encounter and detect many high level infrasound sources on a regular basis, despite their high thresholds.[5] Auditory cortical responses and cochlear modulations to infrasound exposure have also been observed, despite the subjects' lack of tonal perception.[8,9] These studies provide strong evidence for infrasound impact on human peripheral and central auditory responses.

Infrasound impact on inner ear responses

While normal sound perception depends on inner hair cell (IHC) function, human sensitivity to infrasound and low frequencies is thought to rely heavily on outer hair cells (OHCs).[10] Such differential sensitivity between inner and outer hair cells stems from their distinct relationship to the surrounding inner ear structures. Although IHCs and OHCs both sit atop the basilar membrane, the hair (stereovillar) bundles of the OHCs are embedded in the overlying tectorial membrane, unlike those of the IHCs. Instead, IHC hair bundles are bathed in endolymphatic fluid within the subtectorial space and depend on this fluid movement ("squeezing waves") for their stimulation.[11] Mechanical energy must be transferred from the basilar and tectorial membranes to the endolymph to displace the IHC hair bundles. Basilar membrane velocity, however, decreases with decreasing stimulus frequency.[12] At infrasonic frequencies, the low fluid velocity may effectively eliminate IHC hair bundle displacement by fluid motion, rendering IHCs insensitive to infrasound.

In contrast, OHC stereovilli are stimulated directly by the motion of the basilar membrane relative to the tectorial membrane, as they are embedded in the overlying tectorial membrane. The vibrational amplitude of the basilar membrane is proportional to sound pressure level and inversely proportional to frequency.[11-13] OHCs' direct coupling to tectorial membrane movements results in its maintained sensitivity to low-frequency sounds; whereas IHCs' indirect coupling to velocity through fluid movements results in lowered sensitivity. As low-frequency sounds generate significant basilar membrane displacements but low basilar membrane velocities, OHCs are selectively stimulated over IHCs. Furthermore, low-frequency sounds generate minimal endolymphatic viscous forces, allowing maximal stretching of stereovillar tip links for OHC depolarization.[14] It is important, therefore, to keep in mind that high-level, low-frequency stimuli can result in large shearing forces on the OHC stereovilli, but minimal fluid-coupled displacements of IHC stereovilli.

Low-frequency induced OHC intracellular depolarization can be measured as an extracellular voltage change, namely the cochlear microphonic (CM). At 10 Hz (90 dB SPL), CM amplitudes exceed that of the IHC intracellular potentials as a result of basilar membrane displacement.[10,15] CM generation in response to this 10 Hz tone provides concrete evidence for OHC sensitivity to infrasound in the guinea pig. Meanwhile, large CMs generated by OHCs at 40 Hz (112 dB SPL) can electrically stimulate the IHCs to activate type I afferent fibers in the spiral ganglion.[15,16] While type I afferent activation by infrasound has not yet been extensively studied, these data suggest that infrasound has the potential to induce suprathreshold depolarization in IHCs and type I afferent fibers, through large CMs. Subsequent transmission and interpretation of type I afferent signals in the brain would be especially interesting to examine.

In addition to CMs, distortion product otoacoustic emissions (DPOAEs) have also demonstrated human inner ear sensitivity to infrasound. DPOAE recordings allow non-invasive, indirect evaluations of cochlear amplifier characteristics. To elicit DPOAEs, two different pure tones (primaries), f_1 and f_2, are introduced into the ear by placing into the ear canal a sound probe containing two miniature speakers. As the primaries-generated traveling waves propagate along the basilar membrane, they interact and produce additional traveling waves.[17] These waves propagate out of the inner ear, generating DPOAEs that are recorded by a microphone in the sound probe. The most prominent and easily measurable DPOAE in humans and other animals is the cubic difference distortion product, $2f_1$-f_2, typically produced by primary tone ratios (f_2/f_1) between 1.2 to 1.3.[18]

Hensel *et al.* (2007) used primaries of f_1=1.6 and f_2=2.0 kHz (f_2/f_1=1.25) at L_1=51 and L_2=30 dB SPL for their DPOAEs recordings.[8] With the primaries within the normal human audio frequency range, the returning DPOAE represents a typical operating point of the cochlear amplifier. Infrasonic biasing tones (f_b) of 6 Hz, 130 dB SPL and 12 Hz, 115 dB SPL were then introduced and resulting DPOAEs were recorded. When compared to the primaries-only-generated DPOAE pattern, f_b-generated DPOAEs showed significant changes in amplitude and phase due to the shifting of the cochlear amplifier operating point. Since the f_b-generated DPOAE pattern changed relative to the pattern evoked by the primaries-only-generated DPOAES, it may be then concluded that the infrasonic biasing tones had an observable impact on inner ear function.

High level biasing tones provide large vibrational amplitudes that can alter the movement of the cochlear partition, or net pressure across it. The induced pressure gradient in turn shifts the mean position (a DC shift) of the basilar membrane. Such a phenomenon parallels the slow motility mechanism of OHCs. Just as OHC soma contractions alter the dimensions of the subtectorial space to enhance or reduce hearing sensitivity, the shift in basilar membrane position also changes subtectorial volume and adjusts hearing sensitivity. In another words, the gain of the cochlear system can be affected by high level infrasound. Moreover, the modulations seen in f_b-generated DPOAEs reflect differential traveling wave interactions as the result of basilar membrane displacement.

Although the SPLs used for the low-frequency biasing tones approached the pain threshold for human hearing at 1 kHz, the biasing tones did not damage the subjects' cochlear integrity, as shown by consistent primaries-generated DPOAEs before and after biasing tone presentations. None of the subjects reported painful pressure at the eardrum during the experiment. While the biasing tones' high SPLs create large pressure differences in the ear, the sensation of pain may have been reduced by the tones' low vibrational velocity. It was also reported that some subjects perceived a "weak but clearly audible sound sensation, described as humming" but not a "tonal audible stimulus."[7,8,19] The absence of a clear pure-tone percept suggests that infrasonic frequencies do not adequately stimulate the IHCs and hence may not be the sources of the humming. Rather, the source of this percept is likely to be the harmonics of the biasing tone.[20]

Infrasound processing by the auditory pathway

An fMRI study by Dommes *et al.* offers additional insight to infrasound responses in humans.[9] When presented with tones of 12 Hz at 110 and 120 dB SPL, the subjects showed bilateral activation in the primary and secondary auditory cortices (superior temporal gyrus, Brodmann's Area 41, 42, 22). The subjects were also exposed to tones in the human audible frequency range, 500 Hz at 105 dB SPL and 48 Hz at 100 dB SPL. The cortical sites activated for all these frequencies were similar, suggesting that infrasound can have a major impact on brain activation via the auditory pathway. When the 12 Hz tone was reduced to 90 dB SPL, the auditory cortex showed no significant activity, except in one subject. This observation supports the idea of inter-individual differences in low-frequency sensitivity.

Intrinsic noise of fMRI machines can present severe experimental constraints. The scanner noise spectra showed frequencies from 3-10 Hz and 50-900 Hz at levels between 60-75 dB SPL and 60-80 dB SPL, respectively. While infrasound noise remained estimated below threshold,[19] noise between 50-900 Hz was audible and may have affected brain activities. However, Dommes *et al.* believe that the auditory cortex can distinguish and dismiss such background noise.[9] Infrasonic tones must also be presented at high levels in order to overcome fMRI machine background noise. At high levels, the tones produce increased harmonic distortion resulting in high level and more easily detectable harmonics that can potentially alter fMRI results. To evaluate the effects of harmonics, a 36 Hz tone (third harmonic) at 70 dB SPL was presented as a fundamental frequency to the subjects. Auditory cortical activation was observed, though noticeably less than that evoked by a 12 Hz tone at 120 dB SPL. Dommes *et al.* concluded that infrasonic frequencies themselves play significant roles in activating the auditory cortex.[9]

Infrasound exposure on physical and psychological health

Although current research provides no conclusive evidence for infrasound hearing perception by humans, it is nevertheless a worthy exercise to investigate infrasound sources in the immediate environment, as they may contain detectable harmonics. Typical infrasound sources include ocean waves, thunder, wind, machinery engines, slow speed fans, and driving a car with open windows.[5,19] As pure tones are rarely generated in nature, these infrasonic sources typically generate multiple harmonic components and other background noise. It is not unlikely for humans to be exposed to high levels of infrasound. For example, a child on a swing may experience infrasound around 0.5 Hz at 110 dB SPL.[5]

One of the most heavily studied infrasound sources is wind farms. Many wind turbine companies claim that an operating wind farm produces negligible "whooshing" sounds that are comparable only to a kitchen refrigerator around 45 dB SPL.[1,21] However, these claims are based on A-weighted sound analysis, which removes all infrasound components from wind turbine broadband noise. A-weighted filters are inadequate evaluations because they assume human insensitivity to infrasound. Wind turbine spectral analysis by Jung and Cheung has revealed substantial noise levels between 60 to 100 dB SPL for frequencies below 20 Hz.[22] As demonstrated by CMs, DPOAE modulations, and fMRI studies, high levels of infrasound can alter cochlear function and activate the auditory cortex. Potential long term changes in brain activity by nearby wind farms have raised serious concerns. Some physical and psychological health risks from infrasound exposures include the "wind turbine syndrome" and paranormal experiences.[2,10,23,24]

Symptoms of the wind turbine syndrome include sleep disturbance, headache, annoyance, irritability, and chronic fatigue. The symptoms often surface when one is close to wind turbines, or an infrasound source, and disappear when the person moves away. As reported, a family exposed continuously to 10 Hz at 35 dB SPL produced by a boiler house complained of bodily pains, increased annoyance, and difficulties sleeping.[5] This family's high sensitivity to a supposedly subthreshold stimulus supports the notion that inter-individual differences are real and that some individuals are more sensitive and susceptible to the effects of low level infrasound than others. In another study, Pedersen *et al.* interviewed 70,000 adults living within 2.5 km of wind farms.[3] They found that adults exposed to levels of A-weighted noise of 40-50 dB SPL reported higher levels of annoyance than those exposed to levels below 40 dB SPL. Moreover, 12% of the subjects exposed to noise at 40-45 dB SPL reported feeling "very annoyed" versus only 6% from subjects exposed to 35-40 dB SPL; in these cases, individual psychological distress due to wind turbine noise is evident. As audible noise levels increase with increasing proximity to wind turbines, the levels of the infrasonic components also increase. Most subjects described the noise as "swishing/lashing," rather than a pure tone sensation. The discontinuity in sound perception can be attributed the inner ear's increased sensitivity to the infrasonic harmonics, as suggested by Hensel *et al.*'s study.[8] When compared to road traffic noise of similar levels, the subjects reported higher annoyance levels from wind turbines. The high annoyance levels are in part due to the ubiquitous presence of wind turbine sounds throughout the day and night, unlike the road traffic noise which abated at night. Additionally, the inherent, high levels of infrasound in wind turbine noise may also modulate brain activity and increase annoyance levels.

In his famous "ghost-buster" study, Tandy recorded a continuous infrasound emission in a 14th century cellar near Coventry University, England.[2] The cellar has been rumored to be haunted since 1997. Various local visitors reported "very strong feeling of presence," "cold chill," and apparitions upon entering the cellar. Moreover, tourists who have never heard of the rumors also reported paranormal experiences. Tandy's previous study in a supposedly haunted laboratory revealed a steady 18.9 Hz emission by a laboratory machine.[24] Once the machine was turned off, reports of paranormal sensations and sightings also ceased. Assuming a similar phenomenon in the cellar, Tandy used broadband sound level meters and recorded a distinct 19 Hz spectral peak in the ambient noise at 38 dB SPL. Other background infrasound signals were also recorded at very low levels between 7-30 dB SPL. Given the variable sensitivities to ultra-low frequencies demonstrated by Dommes *et al.*,[9] the 19 Hz may have had an effect on sensitive visitors and evoked abnormal experiences.

Since the 19 Hz was significantly below its audible threshold, visitors' paranormal experiences could be due to changes in brain activities, despite the absence of tonal perceptions. It is known that temporal lobe epilepsy patients suffer from high risks of depression, anxiety, irritability, insomnia, and psychosis.[25,26] This suggests that hyper or abnormal activity patterns in the temporal lobe, which includes the primary and secondary auditory cortex, could be linked to the psychiatric symptoms observed in the wind turbine syndrome and paranormal experiences.

Conclusions and future directions for infrasound research

Based on CM and DPOAE modulation studies, infrasonic frequencies can have clear effects on human cochlear state and function. Contrary to the belief that the inner ear does not register infrasound, it was found that infrasound can actually be detected by the OHCs. As OHC slow motility controls hearing sensitivity, the responsiveness of these sensory cells to infrasound could potentially enhance one's ability to perceive infrasound's higher harmonics. Whether OHC-generated CMs can trigger spike generation in IHCs' type I auditory nerve fibers, resulting in direct perception of infrasonic frequencies, is a major research focus today. Infrasound induced OHC activation of auditory nerves presents an alternative pathway of focus, as about 5% of all type I afferent fibers synapse with OHCs.[26] High levels of infrasound have been shown to induce shifts in the basilar membrane position, modulating DPOAE patterns. The shift in basilar membrane parallels the function of OHC slow motility by altering subtectorial space. As changes in subtectorial space affect IHC sensitivity, Hensel *et al.* concluded that infrasound itself can affect the overall gain of the cochlear system.[8]

Knowledge gaps between changes in cochlear function, auditory cortical activity, and sound perception remain. As *in vivo* electrophysiology of human auditory afferent fibers is ethically unacceptable, self-reported sound perceptions and fMRI scans dominate current experimental efforts. While Dommes *et al.* showed significant auditory cortical activity in response to infrasound,[9] additional studies are needed to corroborate their findings. For example, activity in primary somatosensory cortex (Brodmann's Area 2, 3) should be examined and compared to that in the auditory cortex. This would reveal whether the auditory or vestibular pathway plays the more important role in human infrasound detection. In addition, subjects' hearing perceptions during fMRI-infrasound scans should be reported, as done by Hensel *et al.*[8] Since auditory cortical activity increased significantly in response to a 12 Hz tone compared to its lower-level 36 Hz harmonic, infrasound detection in humans may be more common than previously thought. In future experiments, should the subjects report tonal or humming perceptions, along with pronounced auditory cortical activities, then it may be that infrasound itself triggers the perception, as opposed to its harmonics. If the subjects do not report any perceptions, auditory cortical activity could be considered unrelated to the stimulus.

Psychosomatic health risks have been proposed to be the result of infrasound exposure, as changes in temporal lobe activity have been linked to several psychiatric disorders. With nearby communities reporting annoyance toward wind turbine noise, further studies are needed to examine the effects of wind farms on the quality of life in sensitive individuals. Long-term studies on wind turbine noise exposure are also needed. As wind energy is widely accepted for its promising role in clean energy production, putting a hold on wind farm development is highly unlikely. For now, engineering efforts and isolated geographical placements of wind farms serve as the best methods for minimizing community exposure to substantial and potentially harmful levels of wind turbine noise.**AT**

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Annie Chen and friend

Hsuan-hsiu Annie Chen was born in Taipei, Taiwan and moved to San Jose, California when she was ten years old. Annie will be graduating from the University of California, Los Angeles (UCLA) with a B.S. in Neuroscience with honors in spring 2012. In addition, Annie has completed her honors research in bipolar disorder neuroimaging and is an American Heart Association certified cardiopulmonary resuscitation (CPR) and First Aid instructor. In her spare time, Annie enjoys playing tennis, going to Disneyland, and is an occasional freelance event and portrait photographer.

Peter Narins and friend

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EXHIBIT
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Perception-based protection from low-frequency sounds may not be enough

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Hearing and perception in the mammalian ear are mediated by the inner hair cells (IHC). IHCs are fluid-coupled to mechanical vibrations and have been characterized as velocity-sensitive, making them quite insensitive to low-frequency sounds. But the ear also contains more numerous outer hair cells (OHC), which are not fluid coupled and are characterized as displacement sensitive. The OHCs are more sensitive than IHCs to low frequencies and respond to very low-frequency sounds at levels below those that are perceived. OHC are connected to the brain by type II afferent fibers to networks that may further attenuate perception of low frequencies. These same pathways are also involved in alerting and phantom sounds (tinnitus). Because of these anatomic configurations, low-frequency sounds that are not perceived may cause influence in ways that have not yet been adequately studied. We present data showing that the ear's response to low-frequency sounds is influenced by the presence of higher-frequency sounds such as those in the speech frequency range, with substantially larger responses generated when higher-frequency components are absent. We conclude that the physiological effects of low-frequency sounds are more complex than is widely appreciated. Based on this knowledge, we have to be concerned that sounds that are not perceived are clearly transduced by the ear and may still affect people in ways that have yet to be fully understood.

1 INTRODUCTION

The manner in which the inner ear responds to very low-frequency sounds is still not well characterized. The pertinent anatomy and physiology is diagrammed in Figure 1. When sounds enter the cochlea they stimulate different regions, depending on the frequency, or tone, of the sound. The basilar membrane has a low-pass filter characteristic, such that the basal turn can respond to all frequencies while higher frequency components are progressively filtered out towards the apex. The apical regions are where mechanical-to-electrical transduction occurs for

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only the low-frequency components of acoustic sound. Superimposed on the passive mechanical filtering are cochlear hair cells that amplify low-level sounds for detection. This mechanical amplification is performed by the outer hair cells (OHC) so that the signal can be detected by the inner hair cells (IHC) that are the true sensory cells of the ear. The IHCs are densely innervated by type I primary afferent fibers, which is why it is generally accepted that hearing and perception are mediated by IHC activity. An important feature of the IHCs is that their sensory stereocilia ("hairs") do not contact the overlying tectorial membrane. They are therefore fluid coupled to the mechanical vibrations and have been characterized as velocity-sensitive, or ac-coupled[1]. That is to say, high-frequency vibrations stimulate IHCs but low-frequency vibration is attenuated, making IHCs insensitive to very low-frequency sounds. This contributes to the insensitivity of mammalian hearing to very low-frequency sounds and infrasound, requiring high levels to be heard. However, this is not to say that the ear itself is insensitive to very low-frequency sounds and infrasound. The stereocilia of the OHC are directly coupled to the tectorial membrane so they receive mechanical input in a displacement-sensitive manner. In early studies, Békésy[2] showed that displacements of the basilar membrane by trapezoidal stimuli generated trapezoidal response potentials that were sustained for the duration of the stimulus. The OHCs are thus dc-coupled to input and therefore highly sensitive to low-frequency stimulation. The OHC are, in part, connected to the brain by the type II afferents which make up approximately 5% of the afferent fibers in the auditory nerve. Each type II fiber contacts multiple OHC. Although no one has ever reported recordings from type II fibers with infrasound stimulation, Schermuly and Klinke[3] have shown that similar fibers in the bird, that innervate multiple hair cells, are highly sensitive to infrasound input.

Studies have suggested that the perception of low-frequency sounds by humans is influenced by the presence of higher-frequency sounds. Krahé[4,5] found that the perception of low-frequency noise alone was rated to be more annoying than low-frequency noise presented with higher-frequency sounds. These studies suggest that the perceptual consequences of low-frequency sounds should not be studied without considering the combined effects of higher-frequency sounds such as those in the range of speech.

Here we report objective measures from the low-frequency regions of the cochlea. They offer support for hypotheses that the influence of high-frequency sounds on the perception of low-frequency sounds is rooted in a cochlear mechanism in which the OHCs near the apex are stimulated by low frequency sounds more intensely than previously understood.

2 METHODS

Stimulus generation and response acquisition were performed using Tucker-Davis System 3 hardware controlled by custom-written software on a personal computer. Sound stimuli were delivered in a closed system using a hollow ear bar between the transducers and the external ear canal of anesthetized guinea pigs. Full details of stimulus delivery and presentation are given elsewhere[6]. Cochlear responses were measured from 500 mM KCl-filled glass pipettes inserted into endolymph of the cochlear third turn and connected through a high-input impedance electrometer. All procedures were approved by the Animal Studies Committee of Washington University under protocols 20070147 and 20100135.

3 RESULTS

3.1 Suppression of Infrasonic-Tone-Response by a Higher-Frequency Tone

The response of the apical, low-frequency regions of the cochlea to low-frequency sounds is complex. Responses are large when the sound is dominated by low frequencies and become smaller when higher-frequency sounds are present. In Figure 2, the response to an infrasonic (5Hz, 90 dB SPL) tone was recorded from endolymph of the third cochlear turn while a higher frequency (500 Hz) tone was superimposed after 1 second. As the level of the 500 Hz tone was increased from 50 to 80 dB SPL, the response to the 5 Hz stimulus was dramatically suppressed. Suppression of the infrasound response occurred at stimulus levels well below those that saturate the mechanical-to-electrical hair cell transducers of the inner ear (Figure 2, lower left panel), meaning that the suppression is not a result of transducer saturation.

3.2 Low-Pass Noise: A Variant of Infrasonic-Tone-Response Suppression

Responses to low-pass filtered noise were measured with electrodes located in the basal turn (sensitive to high frequency sounds) and in the third cochlear turn (sensitive to low-frequency sounds). All recordings were made with electrodes located in the endolymphatic compartment of the guinea pig inner ear. The sound stimuli used are shown in Figure 3. White noise stimuli were generated and digitally low-pass filtered with a cutoff slope of approximately 55 dB/octave. The noise was digitally generated "frozen noise" so that it had the characteristics of white noise but was exactly repeatable for each of the low-pass filtered conditions, allowing multiple responses to be time-domain averaged. The spectra here were obtained from 20 responses averaged with the noise at a level of 90 dB SPL for the 4 kHz filtered condition. The low-pass cutoff frequency of the filter was varied in half-octave steps from 125 Hz to 4 kHz. Filtered electrical signals sent to the headphone for sound stimulation are shown in the upper panel of Figure 3. These stimuli were delivered by a Sennheiser HD 580 driver and the spectra measured in the canal are shown in the middle panel of Figure 3. For each cutoff frequency the noise levels were measured either with or without filtering the microphone response with a 22 Hz high-pass filter that reduced ambient room noise. The signals were also measured with A-weighting as shown in the lower panel of Figure 3. The noise level for the 125 Hz low-pass filtered condition had an A-weighted level of 56 dB A.

Spectra shown on an expanded frequency scale (0 to 300 Hz) for three simultaneously recorded conditions are shown in Figure 4. Responses measured from the animal are expressed as dB re. 1V where -72 dB represents ~ 250 µV response amplitude. The microphone ear canal measurements of Figure 4, which are the same data as in Figure 3, show that the low-frequency components are indeed frozen, as all measures overlie each other in the 20 – 100 Hz range. The right column of Figure 4 shows the average spectral level over the 12-125 Hz range for each low-pass filter condition. When measured in the basal region of the cochlea, noise with lower frequency cutoff produced larger responses in the low-frequency range. The spectral average over the 12-125 Hz range was approximately 3 dB greater for the 125 Hz cutoff noise than it was with the cutoff set to 2000 Hz, a characteristic that was not present in the simultaneously measured sound levels in the ear canal demonstrating that our inner-ear measures are not an analysis artifact. This same tendency was more pronounced when responses were measured from the third cochlear turn in that the noise with the lowest cutoff frequency generated a substantially larger response. When the response amplitude from the third turn was averaged across the 12-125 Hz range, an approximately 6 dB decline was seen between the 125 Hz and 2000 Hz low-pass filter settings. The results of similar measurements made in 5 animals are summarized in Figure 5. The responses in the low-frequency spectral region (12-125 Hz) were 8.8 dB greater from the 125 Hz low-pass cutoff noise as compared to that from the 2 kHz or higher cutoff frequencies. In other words, *responses from low-frequency stimulus components were 2-3x greater in amplitude when high-frequency sounds were not present.*

3.3 The Effect of A-Weighting

Although the low-pass filtered noise with a cutoff frequency of 2 kHz or greater was set to 90 dB SPL, the measured sound levels decreased, as expected, for stimuli with lower cutoff frequencies as higher frequency components were filtered out. The decline with cutoff frequency, measured in dB SPL, is shown in the lower panel of Figure 3. The changes as cutoff frequency was varied become even more pronounced when the sound was A-weighted. The A-weighted level of the noise with the cutoff filter set at 125 Hz was 56 dB A.

The low frequency responses of the ear, measured as the average spectral components from 12 – 125 Hz, as a function of noise levels is summarized in the left panel of Figure 6. As level was increased, the response from the 125 Hz low-pass filtered noise was always larger than the 4 kHz low-pass filtered noise. In this plot, the sound level represents how the data were collected, based on the noise level for the 4 kHz low-pass (i.e., wide-band) condition. In the right panel, we provide a comparison of the two noise–band responses corrected by A-weighted levels. There are two major observations that result from the comparison in Figure 6 (right panel):

1) **Low-pass filtered noise with a cutoff frequency of 125 Hz presented at a level of ~43 dB A stimulated the apical regions of the cochlea to the same degree as noise with a low-pass cutoff frequency of 4 kHz (i.e. wide band) at a level of 90 dB A.**
2) **At stimulus levels above 45 dB A, 125 Hz low-pass filtered noise generated larger responses at the apical regions of the cochlea than were generated by ANY level of 4 kHz low-frequency cutoff (i.e. wide band) noise.**

4 DISCUSSION AND CONCLUSIONS

The sensitivity of the apical regions of the cochlea to low-frequency sounds, and the suppressive influence of higher frequency sounds on this response, is confirmed by this study. We have demonstrated that A-weighted noise levels of as low as 45 dB A can stimulate apical regions to the same degree as wide band noise of much higher levels, as high as 90 dB A. This study shows that it cannot be assumed that noise levels as low as 40 dB A are benign and do not cause strong stimulation of the ear. Low-frequency noise around 40 dB A undoubtedly affects the ear. If the noise consists of predominantly low frequencies, then it will induce greater stimulation of the ear than has hitherto been appreciated. The observation that responses to primarily low-frequency noise stimulation are larger and do not saturate to the degree seen when higher-frequency components are present (Figure 6) is in complete agreement to the behavior previously seen with tonal stimuli[7]. The input/output functions of cochlear responses saturated at progressively higher levels for 500 Hz, 50 Hz and 5 Hz tonal stimuli presented in quiet. This means that the largest electrical responses in the apical regions of the cochlea will occur specifically when very low-frequency sound dominates the stimulus and mid-frequency components (200 – 2000 Hz) are absent.

The responses from inside the inner ear reported here may provide a physiologic basis for Krahé's psychoacoustical studies that showed how low-frequency noises with sharp cutoff slopes are judged to be more annoying than when presented with higher-frequency sounds, as is the case when lower-cutoff slopes are present[4,5]. Although our studies offer support for Krahé's findings, we do not necessarily agree with his interpretation that the annoyance is mediated by primary type I afferent auditory nerve fibers. We have shown empirically that infrasound rarely leads to direct excitation of single-auditory-nerve afferent fibers [7] and there are many other mechanisms that should not be ruled out, including:

1) Stimulation mediated by type II afferent fibers. Type II fibers innervate multiple OHC and connect to multiple cell types of the cochlear nucleus[8] in the brainstem. These pathways may be inhibitory to conscious hearing[9], and may also be linked to alerting and attention pathways.

2) Cochlear Fluids Disturbances. Low-frequency stimulation at non-damaging levels has been shown to result in a localized endolymphatic hydrops – a swelling of the endolymphatic inner-ear compartment – with associated basally-directed endolymph flow[10]. Wit et al. showed that during endolymph volume increases, pressure changes were consistent with a flow through a narrow duct (the ductus reuniens) into a more compliant chamber (the sacculus)[11]. Histologic studies showed that the sacculus is highly compliant and is one of the first structures affected by endolymphatic hydrops[12]. Low-frequency sound exposure could therefore produce saccular disturbance, with symptoms including unsteadiness and disequilibrium. Furthermore, endolymphatic hydrops has been shown to contribute to an occlusion of the cochlear helicotrema which then makes the ear approximately 20 dB more sensitive to very low-frequency sounds[13]. This leads to the possibility of a positive feedback process, with low-frequency stimulation generating hydrops that in turn makes the ear more sensitive to the low-frequency stimulation. In addition to the mechanical disturbance of the saccule caused by endolymphatic hydrops, saccular enlargement also brings the saccular membranes closer and possibly in contact with the stapes footplate which would result in more efficient, direct stimulation of the saccule.

3) Amplitude modulation of sounds in the acoustic range. We have shown that low-frequency sounds that do not directly stimulate the IHCs and primary afferents, can influence the responses of the auditory nerve (i.e., sounds that will be heard) by inducing a biological form of amplitude modulation[7]. This type of modulation occurs within the cochlea and cannot be measured with a sound level meter. Rather, because the low-frequency displacements of the basilar membrane affect the amplification properties of the OHCs, responses to high-frequency sounds are perceived as being modulated in amplitude.

It is well documented that people find noise with prominent low frequency content annoying[4,5,14]. In the context of wind turbine noise it is known that the larger wind turbines can generate high levels of low frequency noise and infrasound[15,16,17,18,19]. The concern arising from the work we report here is that the cochlear apex of people exposed to such low-frequency sounds will be stimulated to a far greater degree than is suggested by their measured A-weighted sound level. The demonstration that sounds in the range of 40 – 45 dB A may be causing intense stimulation of the cochlear apex has not previously been appreciated. This may account for why the influence of low frequency noise on humans is greater than that estimated from spectral measurements and why consideration of noise crest factors is appropriate[20]. The fact that apical stimulation is maximal when mid- and high-frequency components are absent from the sound may also be important to wind turbine noise effects. It is known that people's houses attenuate sound frequencies in the audible range but have little influence, or may even increase infrasound and low-frequency sound levels[21]. Thus, prolonged periods of exposure to wind turbine noise in an otherwise quiet environment (such as a quiet bedroom) seems to represent a condition in which apical stimulation would be maximized. Intense stimulation of the cochlear apex will certainly have some influence on human physiology. On this basis we think that the concept of “what you can’t hear can’t hurt you” is false. Similarly, there are potential mechanisms by which low-frequency sounds could influence vestibular physiology which are being ignored by some[22]. Our measurements showing that the ear generates large electrical responses to low-frequency stimulation suggest that the effects of low-frequency sound on people living near wind turbines should not be dismissed by those with little understanding of how low frequency sounds indeed affect the ear[19,21,22]. More research on this topic is necessary to enlighten the scientific, medical, and legal communities, and the public, some of whom are being chronically exposed to these sounds.

5 ACKNOWLEDGEMENTS

This work was supported by grant R01 DC001368 from the NIDCD, National Institutes of Health. We thank Jared Hartsock and Ruth Gill for their assistance with the experiments.

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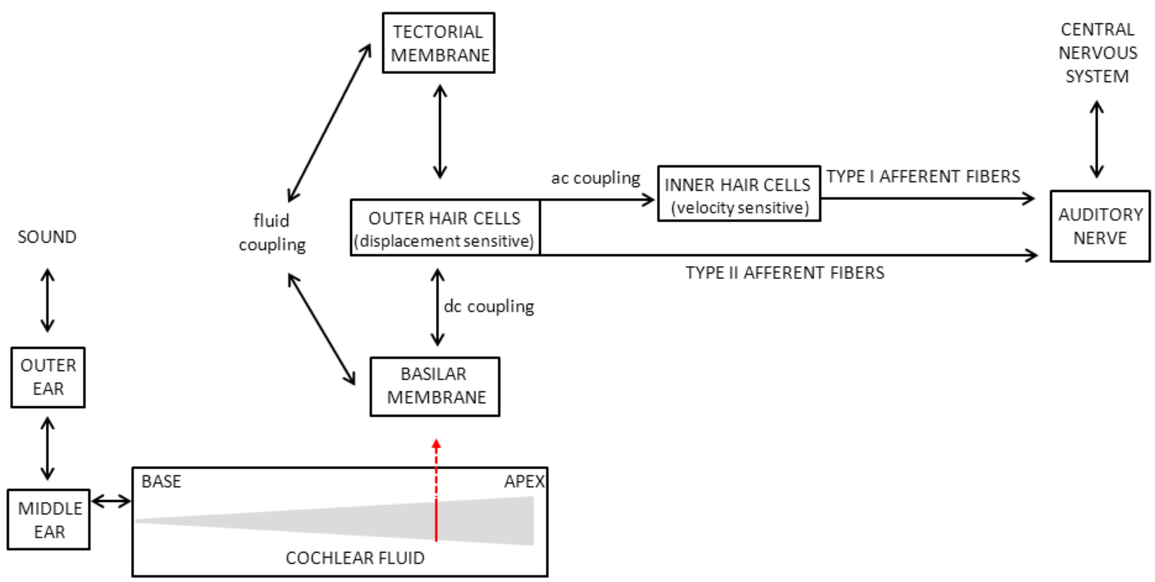

Fig. 1 – Schematic of the auditory periphery. The guinea pig cochlea has 1 row of inner hair cells (IHC) and three rows of outer hair cells (OHC) along its length. The red line and subsequent compartments describe some anatomical and physiological properties of a given segment. After sound propagates through the outer and middle ear, the basilar membrane is set into motion. OHCs in the cochlear apex region respond to low frequencies and are sensitive to the displacement of the basilar membrane motion and are dc-coupled to the sound stimulus. In contrast, the IHC are free within the cochlear fluid causing them to be excited by the velocity of basilar membrane motion, are ac-coupled to the sound stimulus, and are insensitive to low frequency stimulation.

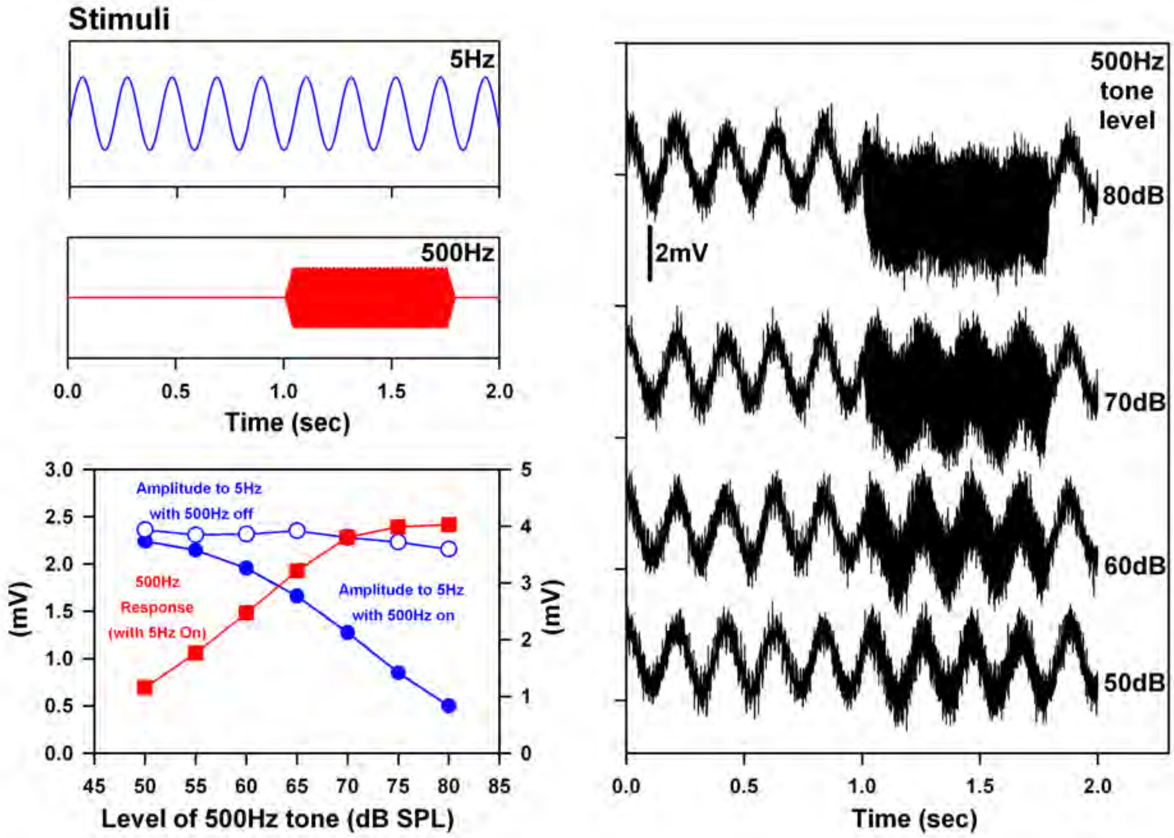

Fig. 2 – Higher-frequency stimuli (500 Hz) suppress the response to a very low-frequency (5 Hz) stimulus. A 500 Hz tone of varied level was superimposed on a 5 Hz, 90 dB stimulus. As the level of the 5 Hz tone was increased, the amplitude of the 5 Hz response declined (right panel).Amplitude measurements (lower left panel) show that 5 Hz stimulation well below saturation (red curve) caused a reduction in response amplitude to the 5 Hz.

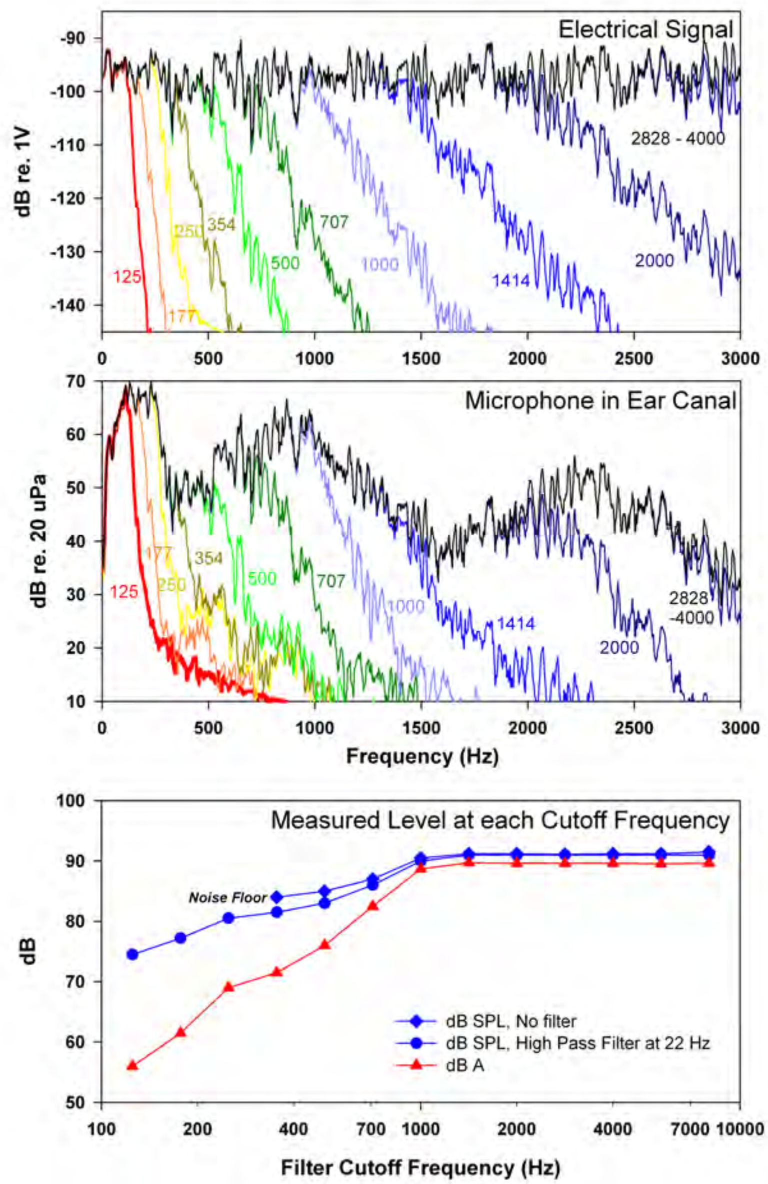

Fig. 3 – Low-pass noise used in this study. The upper panel shows the spectra of low-pass noises with cutoff frequency varied from 125 Hz to 4 kHz. Note that the filter altered the high-frequency component of the noise but had no influence on the low-frequency content (below 100 Hz). The cutoff slope was approximately 55 dB/octave. The middle panel shows the stimuli measured in vivo in the external canal after being delivered by the Sennheiser headphone. The lower panel shows the stimuli with different cutoff frequencies measured in dB SPL and in dB A.

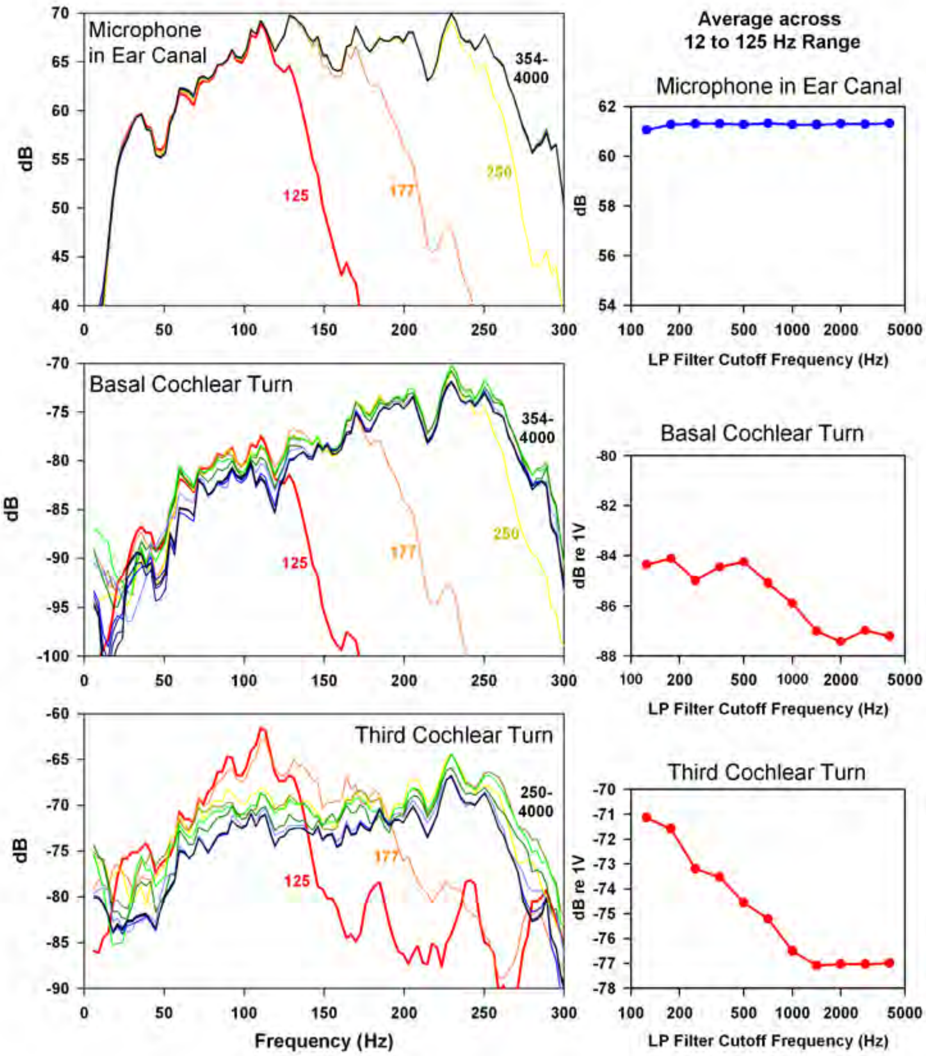

Fig. 4 – Spectra expanded to show the lowest 300 Hz of the frequency range. At each noise filter cutoff frequency, all responses (all 3 panels) were recorded simultaneously to the same stimuli. Top row: The low-frequency region of the sound field showed little variation as cutoff frequency was changed. Middle Row: Responses from the basal cochlear turn were larger when high frequency components were absent. Bottom Row: Apical (Third turn) responses were substantially greater when high frequency components were absent. In this case, the lowest band of noise (125 Hz cutoff) generated ~ 6 dB larger responses than the widest band of noise (4 kHz cutoff). For each condition, the average spectral level in to 12 Hz to 125 Hz range was graphed relative to the noise filter cutoff frequency in the right column.

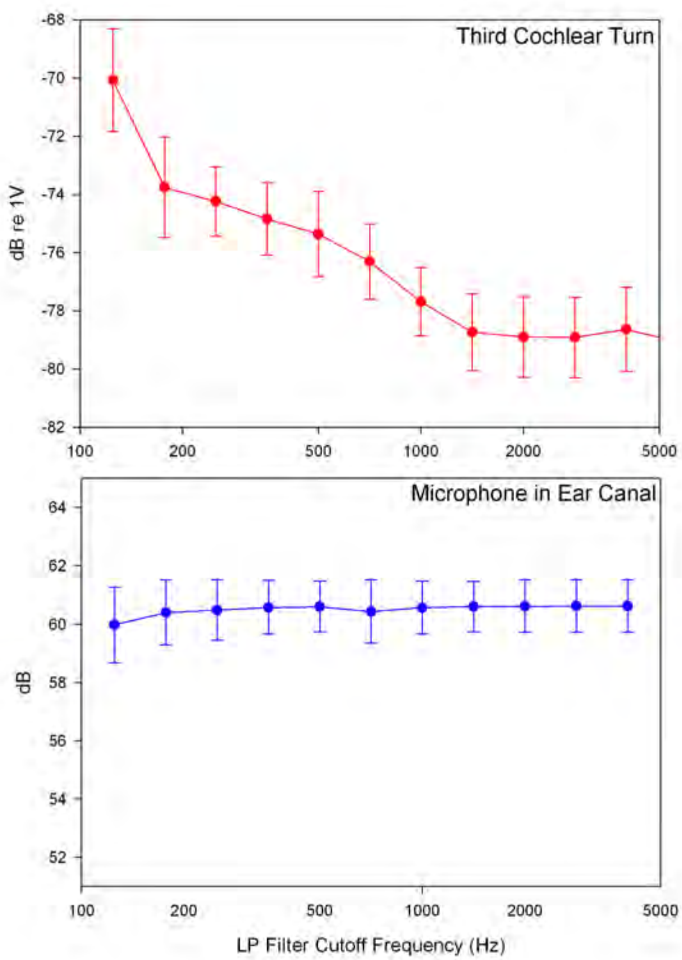

Fig. 5 – Average response amplitudes (+/- SD) in 5 experiments. At each noise cutoff frequency, response amplitude was measured as the average spectral level in the 12 – 125 Hz range. Responses from the apical region of the cochlea showed a systematic decline as noise cutoff frequency is varied, while responses from the microphone, analyzed in an identical manner, did not.

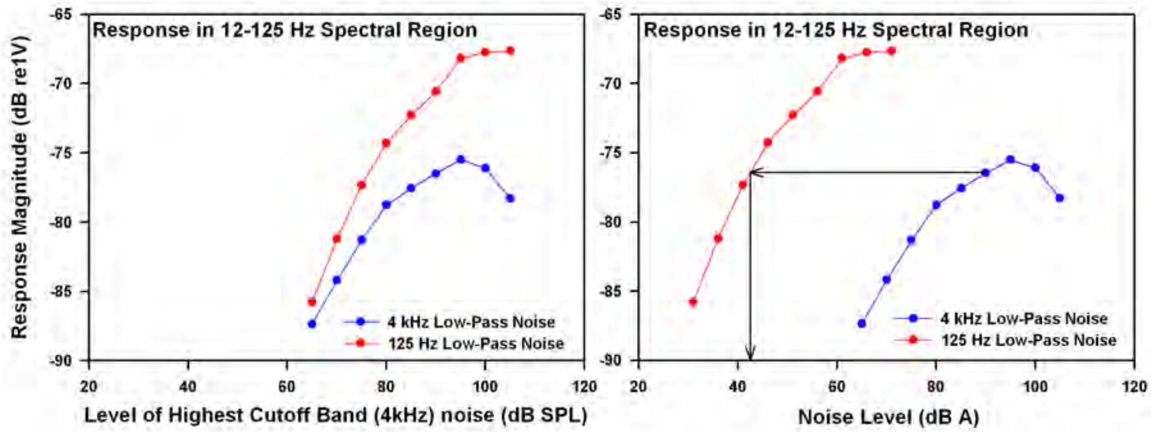

Fig. 6 – ***Left panel:*** *Response amplitudes as the noise level was varied in 5 dB steps. Shown here is only the response amplitudes to the lowest (125 Hz) and highest (4 kHz) noise filter cutoff frequencies used. Amplitudes were the average from the spectrum across the 12 – 125 Hz range (as in Figure 4). Noise with higher frequencies present always generated lower response amplitudes than when higher frequencies were absent. For the 4 kHz band, the responses saturate and decline as level was increased, while the responses to the low-band (125 Hz cutoff) noise keep increasing****. Right panel:*** *The same data plotted based on the A-weighted level of the stimuli measured at each cutoff frequency. This shows that low-frequency noise (125 Hz cutoff) of ~43 dB A generated as large of a response at low frequencies as did a 90 dB A wide band (4 kHz cutoff) noise. Indeed, for 125Hz low-pass noise of 45 dB A or greater, an ear's response will be larger than for wide band noise presented at ANY level.*

EXHIBIT
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Hearing Research 268 (2010) 12–21

Contents lists available at ScienceDirect

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Review Article

Responses of the ear to low frequency sounds, infrasound and wind turbines

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ARTICLE INFO

Article history:
Received 29 April 2010
Received in revised form
7 June 2010
Accepted 9 June 2010
Available online 16 June 2010

ABSTRACT

Infrasonic sounds are generated internally in the body (by respiration, heartbeat, coughing, etc) and by external sources, such as air conditioning systems, inside vehicles, some industrial processes and, now becoming increasingly prevalent, wind turbines. It is widely assumed that infrasound presented at an amplitude below what is audible has no influence on the ear. In this review, we consider possible ways that low frequency sounds, at levels that may or may not be heard, could influence the function of the ear. The inner ear has elaborate mechanisms to attenuate low frequency sound components before they are transmitted to the brain. The auditory portion of the ear, the cochlea, has two types of sensory cells, inner hair cells (IHC) and outer hair cells (OHC), of which the IHC are coupled to the afferent fibers that transmit "hearing" to the brain. The sensory stereocilia ("hairs") on the IHC are "fluid coupled" to mechanical stimuli, so their responses depend on stimulus velocity and their sensitivity decreases as sound frequency is lowered. In contrast, the OHC are directly coupled to mechanical stimuli, so their input remains greater than for IHC at low frequencies. At very low frequencies the OHC are stimulated by sounds at levels below those that are heard. Although the hair cells in other sensory structures such as the saccule may be tuned to infrasonic frequencies, auditory stimulus coupling to these structures is inefficient so that they are unlikely to be influenced by airborne infrasound. Structures that are involved in endolymph volume regulation are also known to be influenced by infrasound, but their sensitivity is also thought to be low. There are, however, abnormal states in which the ear becomes hypersensitive to infrasound. In most cases, the inner ear's responses to infrasound can be considered normal, but they could be associated with unfamiliar sensations or subtle changes in physiology. This raises the possibility that exposure to the infrasound component of wind turbine noise could influence the physiology of the ear.

1. Introduction

The increasing use of wind turbines as a "green" form of energy generation is an impressive technological achievement. Over time, there have been rapid increases in the size of the towers, blades, and generator capacity of wind turbines, as well as a dramatic increase in their numbers. Associated with the deployment of wind turbines, however, has been a rather unexpected development. Some people are very upset by the noise that some wind turbines produce. Wind turbine noise becomes annoying at substantially lower levels than other forms of transportation noise, with the exception of railroad shunting yards (Pedersen and Waye, 2004; Pedersen and Persson Waye, 2007; Pedersen et al., 2009). Some people with wind turbines located close to their homes have reported a variety of clinical symptoms that in rare cases are severe enough to force them to move away. These symptoms include sleep disturbance, headaches, difficulty concentrating, irritability and fatigue, but also include a number of otologic symptoms including dizziness or vertigo, tinnitus and the sensation of aural pain or pressure (Harry, 2007; Pierpont, 2009). The symptom group has been colloquially termed "wind turbine syndrome" and speculated to result from the low frequency sounds that wind turbines generate (Pierpont, 2009). Similar symptoms resulting from low frequency sound emissions from non-wind turbine sources have also been reported (Feldmann and Pitten, 2004).

On the other hand, engineers associated with the wind industry maintain that infrasound from wind turbines is of no consequence if it is below the audible threshold. The British Wind Energy Association (2010), states that sound from wind turbines are in the 30–50 dBA range, a level they correctly describe as difficult to discern above the rustling of trees [i.e. leaves].

This begs the question of why there is such an enormous discrepancy between subjective reactions to wind turbines and the measured sound levels. Many people live without problems near

Abbreviations: CA, cochlear aqueduct; CM, cochlear microphonic; CSF, cerebrospinal fluid; cVEMP, cervical vestibular evoked myogenic potential; EP, endocochlear potential; IHC, inner hair cell(s); oVEMP, ocular vestibular evoked myogenic potential; OHC, outer hair cell(s); RW, round window; ST, scala tympani; SV, scala vestibuli.

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doi:10.1016/j.heares.2010.06.007

noisy intersections, airports and factories where sound levels are higher. The answer may lie in the high infrasound component of the sound generated by wind turbines. A detailed review of the effects of low frequency noise on the body was provided by Leventhall (2009). Although it is widely believed that infrasound from wind turbines cannot affect the ear, this view fails to recognize the complex physiology that underlies the ear's response to low frequency sounds. This review considers the factors that influence how different components of the ear respond to low frequency stimulation and specifically whether different sensory cell types of the inner ear could be stimulated by infrasound at the levels typically experienced in the vicinity of wind turbines.

2. The physics of infrasound

Sounds represent fluctuating pressure changes superimposed on the normal ambient pressure, and can be defined by their spectral frequency components. Sounds with frequencies ranging from 20 Hz to 20 kHz represent those typically heard by humans and are designated as falling within the audible range. Sounds with frequencies below the audible range are termed infrasound. The boundary between the two is arbitrary and there is no physical distinction between infrasound and sounds in the audible range other than their frequency. Indeed, infrasound becomes perceptible if presented at high enough level.

The level of a sound is normally defined in terms of the magnitude of the pressure changes it represents, which can be measured and which does not depend on the frequency of the sound. In contrast, for sounds of constant pressure, the displacement of the medium is inversely proportional to frequency, with displacements increasing as frequency is reduced. This phenomenon can be observed as the difference in vibration amplitude between a subwoofer generating a low frequency tone and a tweeter generating a high frequency tone at the same pressure level. The speaker cone of the subwoofer is visibly displaced while the displacement of the tweeter cone is imperceptible. As a result of this phenomenon, vibration amplitudes to infrasound are larger than those to sounds in the auditory range at the same level, with displacements at 1 Hz being 1000 times those at 1 kHz when presented at the same pressure level. This corresponds to an increase in displacement at a rate of 6 dB/octave as frequency is lowered.

3. Overview of the anatomy of the ear

The auditory part of the inner ear, the cochlea, consists of a series of fluid-filled tubes, spiraling around the auditory nerve. A section through the middle of a human cochlea is shown in Fig. 1A. The anatomy of each turn is characterized by three fluid-filled spaces (Fig. 1B): scala tympani (ST) and scala vestibuli (SV) containing perilymph (yellow), separated by the endolymphatic space (ELS)(blue). The two perilymphatic compartments are connected together at the apex of the cochlea through an opening called the helicotrema. Perilymph is similar in ionic composition to most other extracellular fluids (high Na^+, low K^+) while endolymph has a unique composition for an extracellular fluid in the body, being

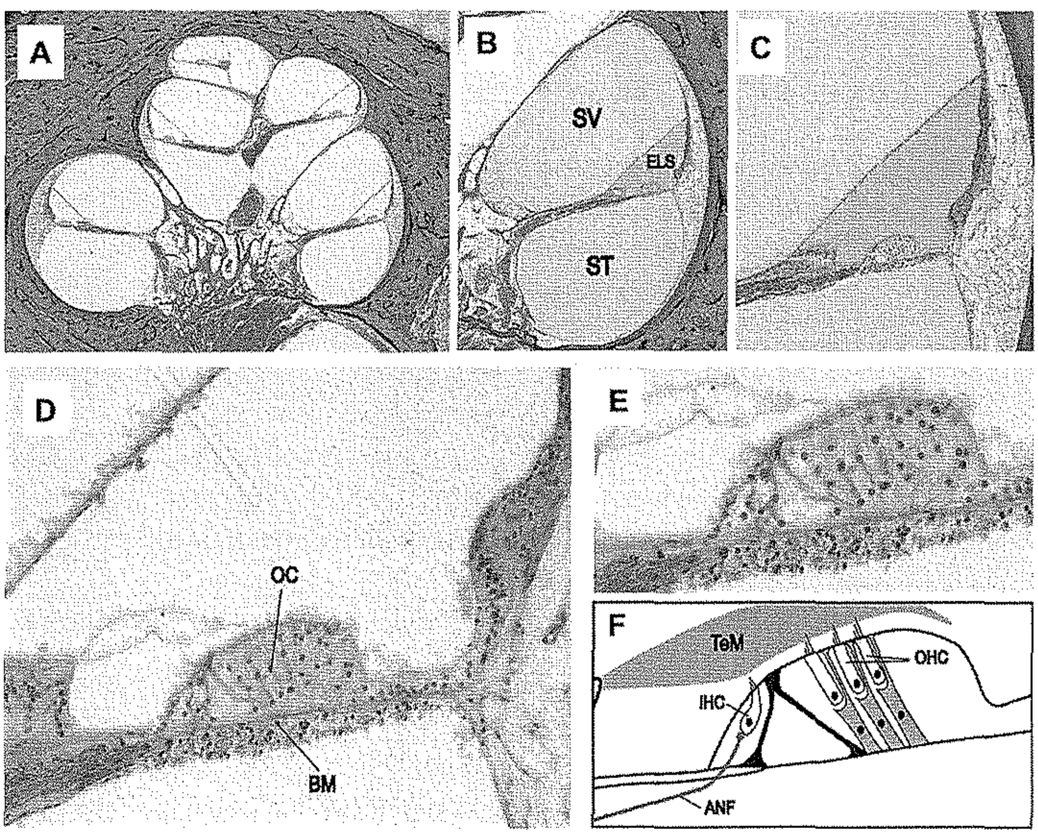

Fig. 1. Panels A–E Cross-section through the human cochlea shown with progressively increasing magnification. Panels B and C The fluid spaces containing perilymph have been colored yellow and endolymph blue. Panel D The sensory structure of the cochlea, the organ of Corti, is colored green. Panel F Schematic showing the anatomy of the main components of the organ of Corti. Abbreviations are: SV: scala vestibuli; ST: scala tympani; ELS: endolymphatic space; OC: organ of Corti; BM: basilar membrane; TeM: tectorial membrane; IHC: inner hair cell; OHC: outer hair cell; ANF: afferent nerve fiber. Original histological images courtesy of Saumil Merchant, MD, Otopathology Laboratory, Massachusetts Eye and Ear Infirmary and Harvard Medical School, Boston.

high in K^+ and low in both Na^+ and Ca^{2+}. It is also electrically polarized by about + 80 mV with respect to perilymph, which is called the endocochlear potential (EP). The main sensory organ of the cochlea (Fig. 1C–E, and shown colored green in Fig. 1D) lies on the basilar membrane between the ELS and the perilymph of ST and is called the organ of Corti. The organ of Corti, seen here in cross section, contains one row of inner hair cells (IHC) and three rows of outer hair cells (OHC) along the spiral length of the cochlea. As shown schematically in Fig. 1F, the sensory hairs (stereocilia) of the OHC have a gradation in length, with the tallest stereocilia embedded in the gelatinous tectorial membrane (TeM) which overlies the organ of Corti in the endolymphatic space (Kimura, 1975). This arrangement allows sound-evoked displacements of the organ of Corti to be converted to a lateral displacement of OHC stereocilia. In contrast, the stereocilia of the IHC do not contact the tectorial membrane, but remain within the fluid of the subtectorial space (Kimura, 1975; Lim, 1986). Because of this difference in how the hair cell stereocilia interact with the TeM, the two types of hair cell respond differently to mechanical stimuli. At low frequencies, the IHC respond according to the velocity of basilar membrane displacement, while OHC respond to the displacement itself (Russell and Sellick, 1983; Dallos, 1984).

The two types of hair cells also contact different types of afferent nerve fibers, sending information to the brain (Spoendlin, 1972; Santi and Tsuprun, 2001). Each IHC is innervated by multiple Type I afferent fibers, with each fiber innervating only a single IHC. The Type I afferents represent the vast majority (95%) of the fibers transmitting information to the brain and as a result it is generally believed that mammals hear with their IHC (Dallos, 2008). In contrast, the OHC contact Type II afferent fibers, which are unmyelinated and make synaptic contacts with a number of OHC. Type II afferents fibers are believed to be unresponsive to sounds and may signal the static position of the organ of Corti (Brown, 1994; Robertson et al., 1999). The OHC also receive substantial efferent innervation (from the brain) while the IHC receive no direct efferent innervation (Spoendlin, 1972).

4. Mechanics of low frequency stimulation

Infrasound entering the ear through the ossicular chain is likely to have a greater effect on the structures of the inner ear than is sound generated internally. The basic principles underlying stimulation of the inner ear by low frequency sounds are illustrated in Fig. 2. Panel A shows the compartments of a simplified, uncoiled cochlea bounded by solid walls with two parallel fluid spaces representing SV and ST respectively that are separated by a distensible membrane representing the basilar membrane and organ of Corti. It is generally agreed that the differential pressure between SV and ST across the basilar membrane is the important factor driving the motion of the basilar membrane (Von Békésy, 1960; Dancer and Franke, 1980; Nakajima et al., 2008; Merchant and Rosowski, 2008). In example A, all the boundaries of the inner ear are solid and noncompliant with the exception of the stapes. In this non-physiologic situation, the stapes applies pressures to SV (indicated by the red arrows) but as the fluid can be considered incompressible, pressures are instantaneously distributed throughout both fluid spaces and pressure gradients across the basilar membrane will be small. In panel B, the round window (RW) and the cochlear aqueduct (CA) have been added to the base of ST. For frequencies below 300 Hz the RW provides compliance between perilymph and the middle ear (Nakajima et al., 2008) and the CA provides fluid communication between perilymph and the cerebrospinal fluid (CSF). Under this condition, pressures applied by the stapes induce small volume flows between the stapes and

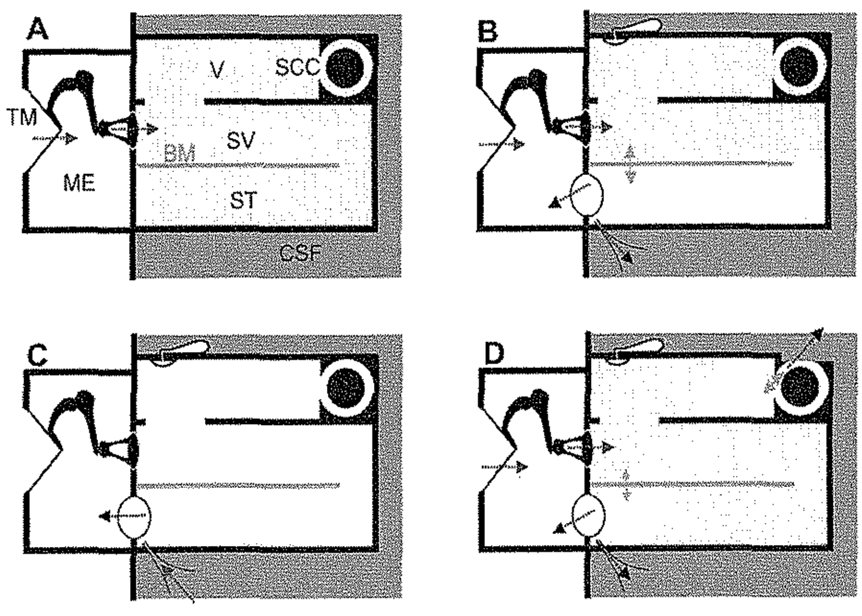

Fig. 2. Schematic representation of the uncoiled inner ear for four different mechanical conditions with low frequency stimulation. Red arrows indicate applied pressure and blue arrows indicate loss to compliant structures. A: indicates a hypothetical condition where the fluid space is rigidly bounded with no "windows" providing compliance. Sound pressure applied by the stapes causes uniform pressures (indicated by color shading) throughout the fluid space, so pressure difference across the basilar membrane and therefore stimulation is minimal. B: The normal situation with compliances provided by the round window and cochlear aqueduct at the base of scala tympani. Pressure differentials cause movement of fluid towards the compliant regions, including a pressure differential across the basilar membrane causing stimulation. C: Situation where low frequency enters scala tympani through the cochlear aqueduct. The main compliant structure is located nearby so pressure gradients across the basilar membrane are small, limiting the amount of stimulation. Infrasound entering through the cochlear aqueduct (such as from respiration and body movements) therefore does not provide the same degree of stimulation as that entering via the stapes. D: Situation with compromised otic capsule, such as superior canal dehiscence. As pressure gradients occur both along the cochlea and through the vestibule and semi-circular canal, the sensory structures in the semi-circular canal will be stimulated. Abbreviations: BM: basilar membrane; CA: cochlear aqueduct; CSF: cerebrospinal fluid; ES: endolymphatic duct and sac; ME: middle ear; RW: round window; SCC: semi-circular canal; ST: scala tympani, SV: scala vestibuli, TM: tympanic membrane; V: vestibule. The endolymphatic duct and sac is not an open pathway but is closed by the tissues of the sac, so it is not considered a significant compliance.

the site(s) of compliance (blue arrows) which requires a pressure gradient to exist along the system, as indicated by the shading. The pressure differential across the basilar membrane will displace it, causing stimulation of the IHC and OHC. This is the situation for external sounds entering the normal cochlea via the ossicular chain. In panel C the situation is compared for sounds originating in the CSF and entering the system through the CA. In this case, the compliant RW is situated close to the location of aqueduct entry, so the major fluid flows and pressure gradients occur locally between these structures. As the stapes and other boundaries in scala vestibuli and the vestibule are relatively noncompliant, pressure gradients across the basilar membrane will be lower than with an equivalent pressure applied by the stapes. For infrasonic frequencies, it was shown that responses to 1 Hz pressure oscillation applied to the fluid in the basal turn of ST were substantially increased when the wall of SV was perforated thereby providing greater compliance in that scala (Salt and DeMott, 1999).

The final condition in Fig. 2D shows the consequences of a "third window" on the SV/vestibule side of the cochlear partition. This causes an increased "air-bone gap" (i.e. an increase in sensitivity to bone conducted vibration and a decreased sensitivity to air conducted sounds, primarily at low frequencies; Merchant and Rosowski, 2008). It may also produce an abnormal sound-induced stimulation of other receptors in the inner ear, such as the hair cells in the ampulla of the semi-circular canal. This is the basis of the Tullio phenomenon, in which externally or internally generated sounds, such as voice, induce dizziness.

Receptors in other organs of the inner ear, specifically both the saccule and the utricle also respond to airborne sounds delivered by the stapes, as discussed in more detail below. The mechanism of hair cell stimulation of these organs is less certain, but is believed to be related to pressure gradients through the sensory epithelium (Sohmer, 2006).

5. Physiologic responses of the ear to low frequency stimuli

5.1. Cochlear hair cells

When airborne sounds enter the ear, to be transduced into an electrical signal by the cochlear hair cells, they are subjected to a number of mechanical and physiologic transformations, some of which vary systematically with frequency. The main processes involved were established in many studies and were summarized by Cheatham and Dallos (2001). A summary of the components is shown in Fig. 3. There are three major processes influencing the sensitivity of the ear to low frequencies. The first arises from the transmission characteristics of sounds through the ossicular structures of the middle ear, which have been shown to attenuate signals at a rate of 6 dB/octave for frequencies below 1000 Hz (Dallos, 1973). As the vibration amplitude in air increases at 6 dB/octave as frequency is lowered, this attenuation characteristic of middle ear transmission results in the displacement of middle ear structures remaining almost constant across frequency for sounds of constant pressure level. A second process attenuating low frequency sounds is the fluid shunting between ST and SV through the helicotrema. The helicotrema has been shown to attenuate frequencies below 100 Hz by 6 dB/octave (Dallos, 1970). The third filter arises from the demonstrated dependence of the IHC on stimulus velocity, rather than displacement (Dallos, 1984). This results in an attenuation of 6 dB/octave for frequencies below approximately 470 Hz for the IHC, and causes a 90° phase difference between IHC and OHC responses (Dallos, 1984). The combined results of these processes are compared with the measured sensitivity of human hearing (ISO226, 2003) in Fig. 3B. The three processes combine to produce the steep decline of sensitivity (up to 18 dB/octave) in human hearing for frequencies between 100 and 20 Hz. This steep cutoff means that to hear a stimulus at 5 Hz it must be presented at 105 dB higher level than one at 500 Hz. This reflects the fact that the predominant, type I afferent fibers are stimulated by the IHC and that mammals hear with their IHC (Dallos, 2008). However, an important consequence of this underlying mechanism is that the OHC and IHC differ markedly in their responses to low frequency stimuli. As the OHC respond to displacement, rather than velocity, they are not subject to the 6 dB/octave attenuation seen by IHC, so at low frequencies they are stimulated by lower sound levels than the IHC. In theory, the difference between IHC and OHC responses will increase as frequency decreases (becoming over 50 dB at 1 Hz), but in practice, there is interaction between the two types of hair cells which limits the difference as discussed below.

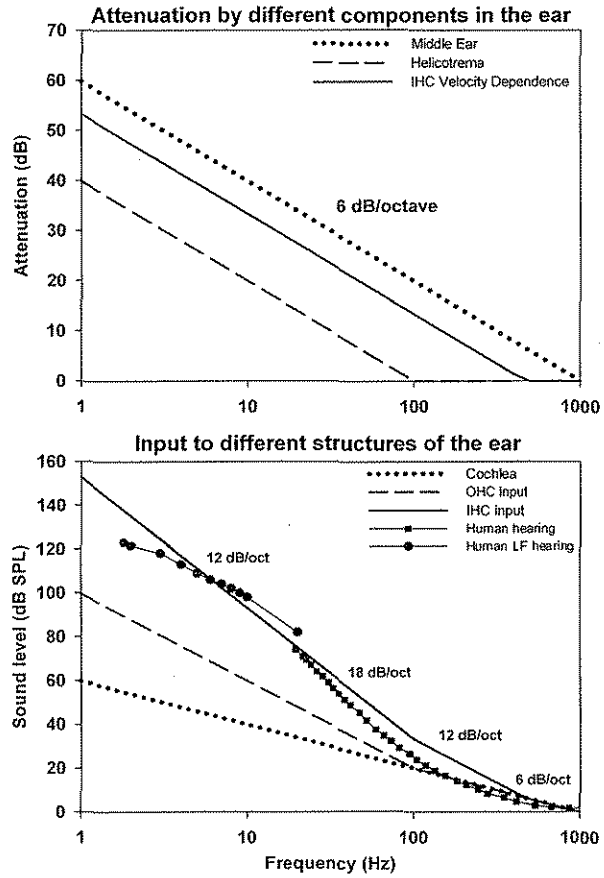

Fig. 3. Upper panel: Estimated properties of high-pass filter functions associated with cochlear signal processing (based on Cheatham and Dallos, 2001). The curves show the low frequency attenuation provided by the middle ear (6 dB/octave below 1000 Hz), by the helicotrema (6 dB/octave below 100 Hz) and by the fluid coupling of the inner hair cells (IHC) resulting in the IHC dependence on stimulus velocity (6 dB/Octave below 470 Hz). Lower panel: Combination of the three processes above into threshold curves demonstrating: input to the cochlea (dotted) as a result of middle ear attenuation; input to the outer hair cells (OHC) as a result of additional filtering by the helicotrema; and input to the IHC as a result of their velocity dependence. Shown for comparison is the sensitivity of human hearing in the audible range (ISO226, 2003) and the sensitivity of humans to infrasounds (Møller and Pederson, 2004). The summed filter functions account for the steep (18 dB/octave) decrease in sensitivity below 100 Hz.

The measured response phase of OHC, IHC and auditory nerve fibers is consistent with the above processes. The cochlear microphonics (CM) recorded in the organ of Corti with low frequency stimuli are in phase with the intracellular potentials of the OHC. This supports the view that the low frequency CM is dominated by

OHC-generated potentials, which follow the displacement of the basilar membrane (Dallos et al., 1972). In contrast, intracellular responses from the IHC lead the organ of Corti CM response by an amount which approaches 90° as frequency is reduced to 100 Hz (Dallos, 1984) corresponding to maximal basilar membrane velocity towards SV (Nuttall et al., 1981). As frequency is lowered, the intracellular potentials of IHC and afferent fiber responses show phase changes consistent with the IHC no longer responding to the increasingly attenuated velocity stimulus, but instead responding to the extracellular potentials generated by the OHC (Sellick et al., 1982; Cheatham and Dallos, 1997). A similar change of phase as frequency is lowered was reported in human psychophysical measurements (Zwicker, 1977) with masking patterns differing by approximately 90° for frequencies above and below 40 Hz. This transition from a response originating from mechanical stimulation of the IHC, to one originating from electrical stimulation of the IHC by large extracellular responses from the OHC may account for the transition of low frequency sensitivity in humans from 18 dB/octave above 20 Hz to 12 dB/octave below 10 Hz (Møller and Pederson, 2004) (Fig. 3B). Near 10 Hz the IHC transition to become primarily stimulated by the more sensitive OHC responses. It can be inferred that if extracellular voltages generated by the OHC are large enough to electrically stimulate the IHC at a specific frequency and level, then the lowest level that the OHC respond to at that frequency must be substantially lower. Based on this understanding of how the sensitivity of the ear arises, one conclusion is that at low frequencies the OHC are responding to infrasound at levels well below those that are heard. On the basis of the calculated input to OHC in Fig. 3B, it is possible that for frequencies around 5 Hz, the OHC could be stimulated at levels up to 40 dB *below* those that stimulate the IHC. Although the OHC at 1 kHz are approximately 12 dB less sensitive than IHC (Dallos, 1984), this difference declines as frequency is lowered and differences in hair cell sensitivity at very low frequencies (below 200 Hz) have not been measured.

Much of the work understanding how the ear responds to low frequency sounds is based on measurements performed in animals. Although low frequency hearing sensitivity depends on many factors including the mechanical properties of the middle ear, low frequency hearing sensitivity has been shown to be correlated with cochlear length for many species with non-specialized cochleas, including humans and guinea pigs (West, 1985; Echteler et al., 1994). The thresholds of guinea pig hearing have been measured with stimulus frequencies as low as 50 Hz, as shown in Fig. 4A. The average sensitivity at 125 Hz for five groups in four studies (Heffner et al., 1971; Miller and Murray, 1966; Walloch and Taylor-Spikes, 1976; Prosen et al., 1978; Fay, 1988) was 37.9 dB SPL, which is 17.6 dB less sensitive than the human at the same frequency and is consistent with the shorter cochlea of guinea pigs. In the absence of data to the contrary, it is therefore reasonable to assume that if low frequency responses are present in the guinea pig at a specific level, then they will be present in the human at a similar or lower stimulus level.

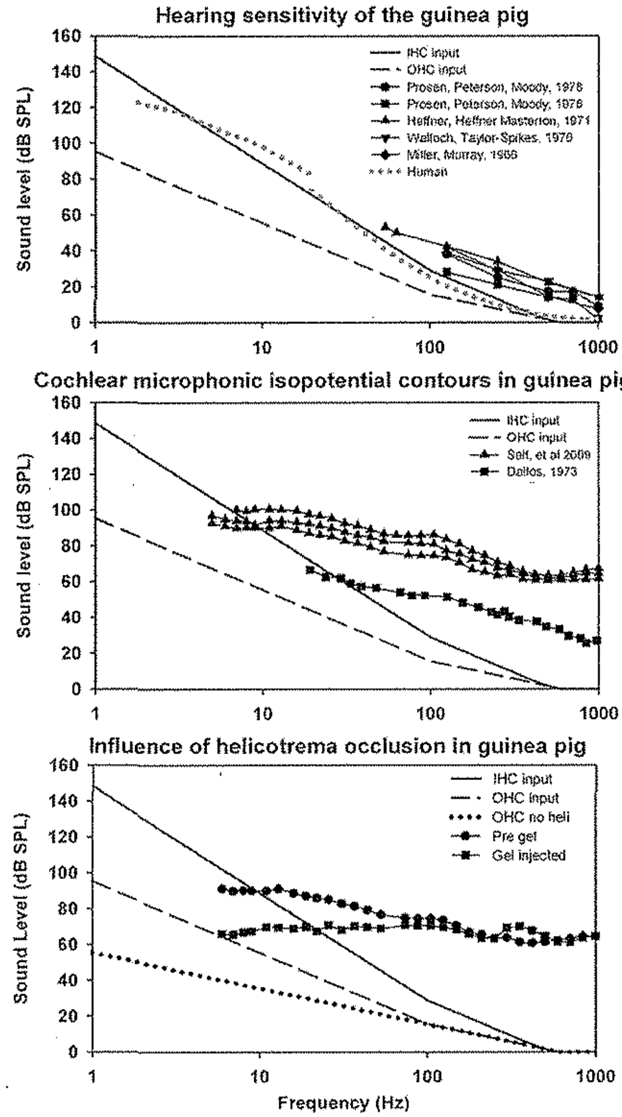

Fig. 4. Upper panel: Similar filter functions as Fig. 3, with parameters appropriate for the guinea pig, and compared with measures of guinea pig hearing. At 125 Hz the guinea pig is approximately 18 dB less sensitive than the human (shown dotted for comparison). Middle panel: Cochlear microphonic isopotential contours in the guinea pig show no steep cutoff below 100 Hz, consistent with input to the OHC being maintained at lower levels than the IHC for low frequencies. Lower panel: Influence of helicotrema occlusion in the guinea pig, produced by injecting 2 μL of hyaluronate gel into the cochlear apex, on the CM isopotential function. Also shown for comparison is the estimated input sensitivity for the OHC with the attenuation by the helicotrema excluded. CM sensitivity curves both have lower slopes than their predicted functions, but the change caused by helicotrema occlusion is comparable.

5.2. Cochlear microphonic measurements

Cochlear microphonics (CM) to low frequency tones originate primarily from the OHC (Dallos et al., 1972; Dallos and Cheatham, 1976). The sensitivity of CM as frequency is varied is typically shown by CM isopotential contours, made by tracking a specified CM amplitude as frequency is varied. Fig. 4B shows low frequency CM sensitivity with two different criteria (Dallos, 1973: 3 μV; Salt et al., 2009: 500 μV). The decrease in CM sensitivity as frequency is lowered notably follows a far lower slope than that of human hearing over the comparable frequency range. In the data from Salt et al. (2009), the stimulus level differences between 5 Hz and 500 Hz average only 34 dB (5.2 dB/octave), compared to the 105 dB difference (15.8 dB/octave) for human hearing over the same range. Although these are suprathreshold, extracellular responses, based on an arbitrary amplitude criterion, these findings are consistent with the OHC having a lower rate of cutoff with frequency than the IHC, and therefore responding to lower level stimuli at very low frequencies.

The measured change in CM sensitivity with frequency may include other components, such as a contribution from transducer adaptation at the level of the OHC stereocilia (Kros, 1996). Kennedy et al. (2003) have suggested that adaptation of the mechano-electrical transducer channels is common to all hair cells and contributes to driving active motion of the hair cell bundle. Based on their measurements in cells isolated from the apical turns of neonatal rats, they estimated that the adaptation caused high-pass filtering with a low frequency cutoff frequency of 2/3 of the best frequency for the cochlear location. This type of adaptation, however, does not appear to provide additional attenuation at very low frequencies, as inferred from CM sensitivity curves measured down to 5 Hz. On the contrary, the CM sensitivity curve appears to flatten below 10 Hz, a phenomenon which is currently under investigation in our laboratory.

Fig. 4C shows the influence of plugging the helicotrema with gel on CM sensitivity with frequency, recorded from the basal turn of a guinea pig with a 500 μV criterion (Salt et al., 2009). These relative sensitivity changes, combined with a 90° phase shift in responses, replicate those of Franke and Dancer (1982) and demonstrate the contribution to attenuation provided by the helicotrema for frequencies below approximately 100 Hz. This contrasts with a prior suggestion that the helicotrema of the guinea pig was less effective than that of other species (Dallos, 1970). While the above CM measurements were made with the bulla open, measurements made in both the bulla open/closed conditions with closed sound-field stimulation suggest there is no pronounced frequency dependence of the difference between these conditions below 300 Hz although there may be a level difference of 5–15 dB (Dallos, 1973; Wilson and Johnstone, 1975).

5.3. *Low frequency biasing, operating point, and distortion generation*

As a result of the saturating, nonlinear transducer characteristic of cochlear hair cells (Russell and Sellick, 1983; Kros, 1996), the fidelity of cochlear transduction depends highly on the so-called operating point of the cochlear transducer, which can be derived by Boltzmann analysis of the CM waveform (Patuzzi and Moleirinho, 1998; Patuzzi and O'Beirne, 1999). The operating point can be regarded as the resting position of the organ of Corti or its position during zero crossings of an applied stimulus (which may not be identical, as stimulation can itself influence operating point). Small displacements of operating point have a dramatic influence on even-order distortions generated by the cochlea ($2f$, f_2–f_1) while having little influence on odd-order distortions ($3f$, $2f_1$–f_2) until displacements are large (Frank and Kössl, 1996; Sirjani et al., 2004). Low frequency sounds (so-called bias tones) have been shown to modulate distortion generated by the ear by their displacement of the operating point of the organ of Corti (Brown et al., 2009). In normal guinea pigs, 4.8 Hz bias tones at levels of 85 dB SPL have been shown to modulate measures of operating point derived from an analysis of CM waveforms (Brown et al., 2009; Salt et al., 2009). This is a level that is substantially below the expected hearing threshold of the guinea pig at 4.8 Hz. In animals where the helicotremea was occluded by injection of gel into the perilymphatic space at the cochlear apex, even lower bias levels (down to 60 dB SPL) modulate operating point measures (Salt et al., 2009). These findings are again consistent with the OHC being the origin of the signals measured and the OHC being more responsive to low frequency sounds than the IHC. A similar hypersensitivity to 4.8 Hz bias tones was also found in animals with surgically-induced endolymphatic hydrops (Salt et al., 2009). This was thought to be related to the occlusion of the helicotrema by the displaced membranous structures bounding the hydropic endolymphatic space in the apical turn. In some cases of severe hydrops, Reissner's membrane was seen to herniate into ST. As endolymphatic hydrops is present both in patients with Meniere's disease and in a significant number of asymptomatic patients (Merchant et al., 2005), the possibility exists that some individuals may be more sensitive to infrasound due the presence of endolymphatic hydrops.

In the human ear, most studies have focused on the $2f_1$–f_2 distortion product, as even-order distortions are difficult to record in humans. The $2f_1$–f_2 component has been demonstrated to be less sensitive to operating point change (Sirjani et al., 2004; Brown et al., 2009). Using different criteria of bias-induced distortion modulation, the dependence on bias frequency was systematically studied in humans for frequencies down to 25 Hz, 6 Hz and 15 Hz respectively (Bian and Scherrer, 2007; Hensel et al., 2007; Marquardt et al., 2007). In each of these studies, the bias levels required were above those that are heard by humans, but in all of them the change of sensitivity with frequency followed a substantially lower slope than the hearing sensitivity change as shown in Fig. 5. Again this may reflect the OHC origins of acoustic emissions, possibly combined with the processes responsible for the flattening of equal loudness contours for higher level stimuli, since the acoustic emissions methods are using probe stimuli considerably above threshold. Although in some regions, slopes of 9–12 dB/octave were found, all showed slopes of 6 dB/octave around the 20 Hz region where human hearing falls most steeply at 18 dB/octave. It should also be emphasized that each of these studies selected a robust modulation criterion and was not specifically directed at establishing a threshold for the modulation response at each frequency. Indeed, in the data of Bian and Scherrer (2007) (their Fig. 3), significant modulation can be seen at levels down to 80 dB SPL at some of the test frequencies. In one of the studies (Marquardt et al., 2007) equivalent measurements were performed in guinea pigs. Although somewhat lower slopes were observed in guinea pigs it is remarkable that stimulus levels required for modulation of distortion were within 5–10 dB of each other for guinea pigs and humans across most of the frequency range. In this case the guinea pig required lower levels than the human. Although the threshold of sensitivity cannot be established from these studies, it is worth noting that for distortion product measurements in the audible range, "thresholds" typically require stimulus levels in the 35–45 dB SPL range (Lonsbury-Martin et al., 1990). In the Marquardt study, the bias tone level required at 500 Hz is over 60 dB above hearing threshold at that frequency.

5.4. *Feedback mechanisms stabilizing operating point*

The OHC not only transduce mechanical stimuli to electrical responses, but also respond mechanically to electrical stimulation

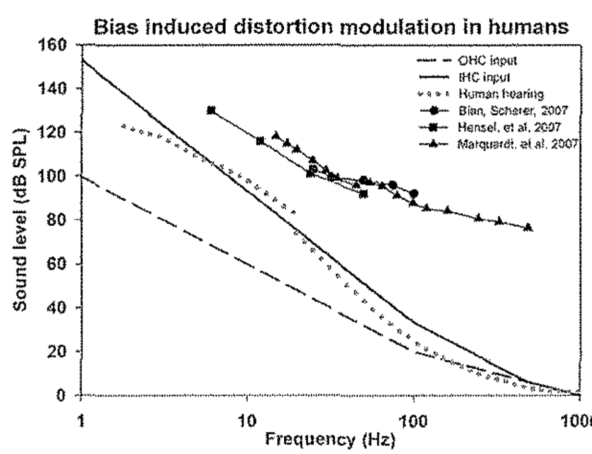

Fig. 5. Frequency dependence of low frequency bias-induced modulation of the $2f_1$–f_2 distortion product measured in the external ear canal of humans in three studies, compared with estimated input functions and human hearing sensitivity. Below 100 Hz the sensitivity to bias falls off at a much lower slope than human hearing, consistent with the response originating from OHC with a lower cutoff slope.

(reviewed by Dallos, 2008) in a manner that provides mechanical amplification. This "active tuning" primarily enhances responses to high stimulus frequencies and is thought to provide little or no active gain with stimuli below approximately 1 kHz (Sellick et al., 2006). For low frequency stimulation, however, basilar membrane modulation by the low frequency tone does have a major influence on the mechanics at the best frequency of high frequency tones i.e. on the active tuning process (Patuzzi et al., 1984). It has been suggested that slow mechanical movements of the OHC may play a part in stabilizing the operating point of the transducer (LePage, 1987, 1989) so the OHC may participate in an active cancellation of low frequency sounds. In models of the cochlear transducer, it was proposed that negative feedback occurred at low frequencies (in which the OHC opposed movements of the basilar membrane), which becomes a positive feedback at the best frequency for the region (Mountain et al., 1983). Chan and Hudspeth (2005) have also suggested OHC motility may be exploited to maintain the operating point of a fast amplifier in the hair cell bundle. However, this possibility has recently been questioned by Dallos (Ashmore et al., 2010) for a number of reasons, one of which is the somatic motor protein, prestin, has an extremely fast response capability. So the interrelationships between hair cell motility and transduction, and between OHC and IHC remain an intense focus of current research. For low frequencies, it has been shown that an out-of phase motion exists between the IHC reticular lamina and the overlying TM so that electromechanical action of the OHC may stimulate the IHC directly, without involvement of the basilar membrane (Nowotny and Gummer, 2006). The possible roles of the OHC and efferent systems are made more complex by recent findings of reciprocal synapses between OHC and their efferent terminals, seen as afferent and efferent synapses on the same fiber (Thiers et al., 2008). One explanation for this system is that the synapses may locally (without involvement of the central nervous system) coordinate the responses of the OHC population so that optimum operating point is maintained for high frequency transduction.

There is some evidence for active regulation of operating point based on the biasing of acoustic emission amplitudes by low frequency tones in which a "hysteresis" was observed (Bian et al., 2004). The hysteresis was thought to result from active motor elements, either in the stereocilia or the lateral wall of the OHC, shifting the transducer function in the direction of the bias. A similar hysteresis was also reported by Lukashkin and Russell (2005) who proposed that a feedback loop was present during the bias that keeps the operating point at its most sensitive region, shifting it in opposite directions during compression and rarefaction phase of the bias tone thereby partially counteracting its effects.

If there are systems in the cochlea to control operating point as an integral component of the amplification process, they would undoubtedly be stimulated in the presence of external infrasound.

5.5. *Vestibular function*

The otolith organs, comprising of the saccule and utricle, respond to linear accelerations of the head (Uzun-Coruhlu et al., 2007) and the semi-circular canals respond to angular acceleration. These receptors contribute to the maintenance of balance and equilibrium. In contrast to the hair cells of the cochlea, the hair cells of the vestibular organs are tuned to very low frequencies, typically below 30 Hz (Grossman et al., 1988). Frequency tuning in vestibular hair cells results from the electrochemical properties of the cell membranes (Manley, 2000; Art and Fettiplace, 1987) and may also involve active mechanical amplification of their stereociliary input (Hudspeth, 2008; Rabbitt et al., 2010). Although vestibular hair cells are maximally sensitive to low frequencies they typically do not respond to airborne infrasound. Rather, they normally respond to mechanical inputs resulting from head movements and positional changes with their output controlling muscle reflexes to maintain posture and eye position. At the level of the hair cell stereocilia, although vibrations originating from head movements and low frequency sound would be indistinguishable, the difference in sensitivity lies in the coupling between the source stimulus and the hair cell bundle. Head movements are efficiently coupled to the hair cell bundle, while acoustic stimuli are inefficiently coupled due to middle ear characteristics and the limited pressure gradients induced within the structure with sound stimuli (Sohmer, 2006).

In a similar manner to cochlear hair cells, which respond passively (i.e. without active amplification) to stimuli outside their best frequency range, vestibular hair cells respond passively to stimuli outside their best frequency range. The otolith organs have been shown to respond to higher, acoustic frequencies delivered in the form of airborne sounds or vibration. This has been demonstrated in afferent nerve fiber recordings from vestibular nerves (Young et al., 1977; McCue and Guinan, 1994; Curthoys et al., 2006) and has recently gained popularity as a clinical test of otolith function in the form of vestibular evoked myogenic potential (VEMP) testing (Todd et al., 2003; Zhou and Cox, 2004; Curthoys, 2010).These responses arise because higher frequency stimuli are more effectively coupled to the otolithic hair cells. But as sound or vibration frequency is reduced, its ability to stimulate the vestibular organs diminishes (Murofushi et al., 1999; Hullar et al., 2005; Todd et al., 2008). So for very low frequencies, even though the hair cell sensitivity is increasing as active tuning is invoked, mechanical input is being attenuated. While there have been many studies of vestibular responses to physiologic stimuli (i.e. head accelerations, rotations, etc) comprising of infrasonic frequency components, we are unaware of any studies that have directly investigated vestibular responses to airborne infrasound of similar frequency composition. As people do not become unsteady and the visual field does not blur when exposed to high-level infrasound, it can be concluded that sensitivity is extremely low.

In some pathologic conditions, coupling of external infrasound may be greater. It is known that "third window" defects, such as superior canal dehiscence increase the sensitivity of labyrinthine receptors to sounds (Wit et al., 1985; Watson et al., 2000; Carey et al., 2004), and are exhibited as the Tullio phenomenon (see earlier section). To our knowledge, the sensitivity of such patients to controlled levels of infrasound has never been evaluated. In this respect, it needs to be considered that vestibular responses to stimulation could occur at levels below those that are perceptible to the patient (Todd et al., 2008).

5.6. *Inner ear fluids changes*

Some aspects of cochlear fluids homeostasis have been shown to be sensitive to low frequency pressure fluctuations in the ear. The endolymphatic sinus is a small structure between the saccule and the endolymphatic duct which has been implicated as playing a pivotal role in endolymph volume regulation (Salt, 2005). The sinus has been shown to act as a valve, limiting the volume of endolymph driven into the endolymphatic sac by pressure differences across the endolymphatic duct (Salt and Rask-Andersen, 2004). The entrance of saccular endolymph into the endolymphatic sac can be detected either by measuring the K^+ concentration in the sac (as saccular endolymph has substantially higher K^+ concentration) or by measuring hydrostatic pressure. The application of a sustained pressure to the vestibule did not cause K^+ elevation or pressure increase in the sac, confirming that under this condition, flow was prevented by the membrane of the sinus acting as a valve. In contrast, the application of 5 cycles at 0.3 Hz to the external ear canal, caused a K^+ increase in the sac, confirming that oscillation of pressure applied to the sinus allowed pulses of endolymph to be driven from the sinus into the endolymphatic sac. The pressure changes driving these pulses was large, comparable to those produced by contractions of the tensor tympani muscle, as occurs during swallowing. Tensor tympani contractions produce displacements of the stapes towards the vestibule for a duration of approximately 0.5 s (~2 Hz), which induce large EP changes and longitudinal movements of endolymph within the cochlea (Salt and DeMott, 1999). The lowest sound level that drives endolymph movements is currently unknown.

A therapeutic device (the Meniett: www.meniett.com; Odkvist et al., 2000) that delivers infrasound to the inner ear is widely used to treat Meniere's disease in humans (a disease characterized by endolymphatic hydrops). The infrasonic stimulus (6 Hz or 9 Hz) is delivered by the device in conjunction with sustained positive pressure in the external canal. An important aspect of this therapy, however, is that a tympanostomy tube is placed in the tympanic membrane before the device is used. The tympanostomy tube provides an open perforation of the tympanic membrane which shunts pressure across the structure, so that ossicular movements (and cochlear stimulation) are minimized, and the pressures are applied directly to the round window membrane. Nevertheless, the therapeutic value of this device is based on infrasound stimulation influencing endolymph volume regulation in the ear.

As presented above, endolymphatic hydrops, by occluding the perilymph communication pathway through the helicotrema, makes the ear more sensitive to infrasound (Salt et al., 2009). It has also been shown that non-damaging low frequency sounds in the acoustic range may themselves cause a transient endolymphatic hydrops (Flock and Flock, 2000; Salt, 2004). The mechanism underlying this volume change has not been established and it has never been tested whether stimuli in the infrasound range cause endolymphatic hydrops.

Although infrasound at high levels apparently does not cause direct mechanical damage to the ear (Westin, 1975; Jauchem and Cook, 2007) in animal studies it has been found to exacerbate functional and hair cell losses resulting from high level exposures of sounds in the audible range (Harding et al., 2007). This was explained as possibly resulting from increased mixture of endolymph and perilymph around noise induced lesion sites in the presence of infrasound.

6. Wind turbine noise

Demonstrating an accurate frequency spectrum of the sound generated by wind turbines creates a number of technical problems. One major factor that makes understanding the effects of wind turbine noise on the ear more difficult is the widespread use of A-weighting to document sound levels. A-weighting shapes the measured spectrum according to the sensitivity of human hearing, corresponding to the IHC responses. As we know the sensitivity for many other elements of inner ear related to the OHC do not decline at the steep slope seen for human hearing, then A-weighting considerably underestimates the likely influence of wind turbine noise on the ear. In this respect, it is notable that in none of the physiological studies in the extensive literature reporting cochlear function at low frequencies were the sound stimuli A-weighted. This is because scientists in these fields realize that shaping sound levels according to what the brain perceives is not relevant to understanding peripheral processes in the ear. A-weighting is also performed for technical reasons, because measuring unweighted spectra of wind turbine noise is technically challenging and suitable instrumentation is not widely available. Most common approaches to document noise levels (conventional sound level meters, video cameras, devices using moving coil microphones, etc) are typically insensitive to the infrasound component. Using appropriate instrumentation, Van den Berg showed that wind turbine noise was dominated by infrasound components, with energy increasing between 1000 Hz and 1 Hz (the lowest frequency that was measured) at a rate of approximately 5.5 dB/octave, reaching levels of approximately 90 dB SPL near 1 Hz Sugimoto et al. (2008) reported a dominant spectral peak at 2 Hz with levels monitored over time reaching up to 100 dB SPL. Jung and Cheung (2008) reported a major peak near 1 Hz at a level of approximately 97 dB SPL. In most studies of wind turbine noise, this high level, low frequency noise is dismissed on the basis that the sound is not perceptible. This fails to take into account the fact that the OHC are stimulated at levels that are not heard.

7. Conclusions

The fact that some inner ear components (such as the OHC) may respond to infrasound at the frequencies and levels generated by wind turbines does not necessarily mean that they will be perceived or disturb function in any way. On the contrary though, if infrasound is affecting cells and structures at levels that cannot be heard this leads to the possibility that wind turbine noise could be influencing function or causing unfamiliar sensations. Long-term stimulation of position-stabilizing or fluid homeostasis systems could result in changes that disturb the individual in some way that remains to be established. We realize that some individuals (such as fighter pilots) can be exposed to far higher levels of infrasound without undue adverse effects. In this review, we have confined our discussion to the possible direct influence of infrasound on the body mediated by receptors or homeostatic processes in the inner ear. This does not exclude the possibility that other receptor systems, elsewhere in the body could contribute to the symptoms of some individuals.

The main points of our analysis can be summarized as follows:

1) Hearing perception, mediated by the inner hair cells of the cochlea, is remarkably insensitive to infrasound.
2) Other sensory cells or structures in the inner ear, such as the outer hair cells, are more sensitive to infrasound than the inner hair cells and can be stimulated by low frequency sounds at levels below those that are heard. The concept that an infrasonic sound that cannot be heard can have no influence on inner ear physiology is incorrect.
3) Under some clinical conditions, such as Meniere's disease, superior canal dehiscence, or even asymptomatic cases of endolymphatic hydrops, individuals may be hypersensitive to infrasound.
4) A-weighting wind turbine sounds underestimates the likely influence of the sound on the ear. A greater effort should be made to document the infrasound component of wind turbine sounds under different conditions.
5) Based on our understanding of how low frequency sound is processed in the ear, and on reports indicating that wind turbine noise causes greater annoyance than other sounds of similar level and affects the quality of life in sensitive individuals, there is an urgent need for more research directly addressing the physiologic consequences of long-term, low level infrasound exposures on humans.

Acknowledgments

This work was supported by research grant RO1 DC01368 (2005–2010) and KO8 DC 006869 (2004–2010) from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health.

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SCIENTIFIC REPORTS

OPEN

Exposure to Magnetic Field Non-Ionizing Radiation and the Risk of Miscarriage: A Prospective Cohort Study

Received: 14 August 2017
Accepted: 10 November 2017
Published online: 13 December 2017

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Magnetic field (MF) non-ionizing radiation is widespread and everyone is exposed to some degree. This prospective cohort study of 913 pregnant women examined the association between high MF exposure and miscarriage risk. Cox (proportional hazards) regression was used to examine the association. After controlling for multiple other factors, women who were exposed to higher MF levels had 2.72 times the risk of miscarriage (hazard ratio = 2.72, 95% CI: 1.42–5.19) than those with lower MF exposure. The increased risk of miscarriage associated with high MF was consistently observed regardless of the sources of high MF. The association was much stronger if MF was measured on a typical day of participants' pregnancies. The finding also demonstrated that accurate measurement of MF exposure is vital for examining MF health effects. This study provides fresh evidence, directly from a human population, that MF non-ionizing radiation could have adverse biological impacts on human health.

Magnetic fi ld (MF) non-ionizing radiation is a ubiquitous environmental exposure and a serious looming public health challenge. MFs are emitted from both traditional sources that generate low frequency MFs (e.g., power lines, appliances, transformers, etc.) and from emerging sources that generate higher frequency MFs (e.g., wireless networks, smart meter networks, cell towers, wireless devices such as cell phones, etc.). Humans are now widely exposed to MF with ever-increasing intensity, due to the proliferation of MF-generating apparatuses.

The steep increase in MF exposure has renewed concerns about the potential health effects of this invisible, man-made environmental exposure. A recent NIEHS multi-year project conducted by the National Toxicology Program (NTP) has revealed an increased risk of cancer associated with MF non-ionizing radiation exposure[1,2]. More specifi ally, the NTP study found that the cancer risk due to MF exposure observed in their experimental animals matched the cancer cell types that had been reported in previous epidemiologic studies in human populations[1]. Th s fi ding has made it more difficult to continue to dismiss possible biological effects of MF exposure. Such outright dismissal could be especially troublesome given the high prevalence of human exposure (with almost everyone being exposed to MF non-ionizing radiation to some degree). Th s includes vulnerable populations such as pregnant women and young children. The International Agency for Research on Cancer (IARC) has classifi d MF as a possible carcinogen[3,4].

Miscarriage is one of the potential adverse health outcomes that are sensitive to MF exposure and also an endpoint that the WHO has recommended to be further studied in the context of MF health effects[5]. Over the years, a few observational studies in human populations have suggested a possible link between MF exposure during pregnancy and an increased risk of miscarriage[6–11] including two studies published in 2002 that increased the public awareness of such an association[12,13]. In addition, one study examined human embryonic tissues to assess the association between EMF exposure and embryonic growth, and observed an increased risk of impaired embryonic bud growth and apoptosis associated with exposure to higher MF level[14], providing some direct evidence of adverse biological impact of EMF exposure on embryonic development.

Nevertheless, the association between MF exposure and risk of miscarriage remains largely unknown and overlooked. We conducted this prospective cohort study among a large population of pregnant women to further examine whether exposure to MF non-ionizing radiation during pregnancy increases the risk of miscarriage.

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Materials and Methods

Th s prospective cohort study was approved by the Kaiser Permanente Northern California (KPNC) Institutional Review Board and conducted among KPNC's pregnant members in the San Francisco Bay Area, all of whom provided informed consent. The study was performed in accordance with all relevant guidelines and regulations. KPNC is an integrated health care delivery system whose members comprise 28–30% of the population in the catchment area and have consistently been shown to be representative of the underlying population[15,16].

Study population. All pregnant women, aged 18 years or older, and residing in the participating Bay Area counties, were identifi d through the KPNC electronic medical record (EMR) laboratory database based on positive pregnancy tests. At KPNC, all women suspected to be pregnant were routinely asked to have a pregnancy test done at a KPNC facility. Flyers informing women about the study were posted at the participating facilities and given to women at the time of their pregnancy test. Given that miscarriage can occur very early in pregnancy, recruiting pregnant women as early as possible in their pregnancy was crucial to ensuring as complete ascertainment of miscarriage as possible. Our identifi ation of pregnant women through positive pregnancy lab tests ensured early recruitment. To determine whether a woman's recurrent miscarriage(s), an indication of higher susceptibility to miscarriage, increases her vulnerability to MF exposure, we oversampled women with two or more prior miscarriages. The pregnant women identifi d were contacted by a trained recruiter/interviewer to determine their eligibility and willingness to participate in the study. Those who indicated their intention to carry the pregnancy to term and whose gestational age at identifi ation was less than 10 completed weeks (still at risk for miscarriage) were invited to participate in the study. Among 1,627 eligible pregnant women, 1,054 agreed to participate in the study.

Measuring magnetic field exposure during pregnancy. All participating pregnant women were asked to carry an EMDEX Lite meter (Enertech Consultants Inc.) for 24 hours during pregnancy. The EMDEX Lite meter is specifi ally designed to measure MF, which is measured in milligauss (mG).

To ensure better representation of MF exposure during pregnancy and to apply the knowledge gained from the previous study[12], we designed the MF measurement to be conducted on a typical day (a day refl cting participants' typical pattern of work and leisure activities during pregnancy). In the event that a participant's daily activities might have been altered from what was originally planned, we also verifi d with the participants, at the end of the measurement period, whether the measurement day was indeed a typical day of their pregnancy. If not, the measurement day was classifi d as non-typical.

The EMDEX Lite meter was used to measure MF exposure levels by participating pregnant women from all emitting sources. Participants were also asked to keep a diary during the 24-hour measurement period to allow the researchers to (1) identify locations of daily activities (at home, at home in bed, in transit, at work, and other), (2) verify if activities were refl ctive of a typical day, and (3) examine if locations and activities were associated with high MF exposure.

MF data together with participants' diary of activities on the measurement day were examined for quality control, including consistency and potential errors. We excluded 31 subjects who failed to carry the meter as instructed. We also excluded 107 subjects who had incomplete (<90% of their 24-hour measurements) MF measurement data. Those exclusions were made without knowledge of subjects' pregnancy outcomes.

Previous studies have found that the highest MF levels that pregnant women encounter are the most relevant to miscarriage risk[12,13], indicating a possible threshold effect at a given MF level above which developmental embryos may cease to be viable. Thus, this study focused on high levels of MF exposure. We used the 99^{th} percentile of MF measurements during the 24-hour period to classify exposure level, balancing between the need to examine as high of MF level as possible and, at the same time, avoid using less stable indices (e.g., maximum exposure level).

To more accurately refl ct participants' true MF exposure during pregnancy, we made signifi ant efforts to separate those participants whose measurements were conducted during a typical day of their pregnancy from those whose measurements were not conducted on a typical day. Measurements obtained on a ***typical day*** are likely more representative of MF exposure during pregnancy while measurements obtained on a *non-typical* day are more subject to misrepresentation of the true MF exposure level during pregnancy, resulting in misclassifying participants into incorrect MF exposure categories. Such misclassifi ation usually reduces scientists' ability to detect an underlying association. As demonstrated in a previous study, measurements conducted on a typical day showed a stronger association between MF exposure and miscarriage risk, while measurements conducted on a non-typical day showed virtually no association due to incorrectly classifying participants into MF exposure categories[12].

Measurement of miscarriage. Using KPNC EMR data, we were able to identify participants' pregnancy immediately after a positive pregnancy test, thereby starting follow-up at an earlier gestational age than the fi st prenatal visit, the earliest time at which most other studies have been able to identify pregnant women. Th s early follow-up allowed us to ascertain early miscarriages that most other studies would have missed, making it an important strength of this study.

All participants were followed for their pregnancy outcomes from the time of their positive pregnancy test to the end of their pregnancy. In the case of miscarriage, this is, by defin tion, before 20 completed weeks of gestation. We ascertained pregnancy outcomes through the KPNC EMR databases. For participants whose outcomes were not available in the EMR, we contacted them directly. We were able to identify pregnancy outcomes for all participants except one who had moved out of the area, thus she was excluded from further analysis.

In-person interview. An *in-person* interview was conducted with all participants to ascertain extensive information on potential confounders, including pregnancy history and risk factors for miscarriage. Previous studies have shown that MF exposure level is seldom related to common socio-demographic characteristics and risk factors[12,17,18]; thus, the number of potential confounders in this study was small. Nevertheless, we still collected many factors for examination to ensure thorough control of confounders. Two participants were not able to complete the interview, thus they were excluded from the analyses.

The prospective study design also ensured that the *in-person* interview was blinded to MF exposure for both interviewers and participants, since the EMF measurement was conducted after the interview. Th s study design enhances the quality of the study fi dings.

Statistical analysis. We used the Cox Proportional Hazards regression model, with accommodation for left truncation, to examine the association between MF exposure level and miscarriage. Hazard ratios with 95% confide ce intervals were used to determine the magnitude and signifi ance of associations. Left truncation arises when study participants enter observation at a point in time (i.e. gestational age at cohort entry) after the time of origin, conception. Participants were followed until either (a) miscarriage, (b) end of pregnancy due to other outcomes (e.g., ectopic pregnancy), at which point they were censored or (c) 20 weeks of gestation, for participants who remained pregnant at that time.

We examined confounders using the change-in-estimate criterion, including the confounder if the miscarriage hazard ratio (HR) for MF changed by 10% or more. While most factors examined were not confounders due to a lack of association with MF exposure, we nevertheless included in the model commonly known risk factors for miscarriage and socio-demographic characteristics.

Given the previous fi ding that the strength of association between MF and miscarriage varied by whether the MF measurements were taken on a typical or non-typical day[12], we fi st conducted analyses separately by day type. The previous fi ding was confi med in the current study, and we therefore conducted the remaining analyses only among those whose MF exposure was measured on ***a typical day*** of their pregnancy.

Since we oversampled those with multiple prior miscarriages, we fi st stratifi d analysis by those with and without multiple prior miscarriages to determine if the MF association with miscarriage risk differed between these two groups. Once it was determined that the observed associations were largely similar, we included all participants in the analyses and adjusted for prior miscarriage in all the models.

A total of 913 subjects with valid MF measurements and pregnancy outcomes were included in the fi al analysis.

Statistical analyses were conducted using SAS 9.3.

Results

Table 1 presents the description and characteristics of participants based on their MF exposure levels (high vs. low). The low MF exposure group consisted of women whose 99th percentile of MF exposure levels was in the lowest quartile (<2.5 mG), while those in the higher three quartiles were classifi d in the high MF exposure group. There were no noticeable associations or consistent patterns between MF exposure level and most of the factors examined, including risk factors for miscarriage (Table 1).

After adjustment for maternal age, race, education, smoking during pregnancy, and prior miscarriage, overall, pregnant women who had higher MF exposure during pregnancy (higher 3 quartiles) had a 48% greater risk of miscarriage than women who had lower MF exposure (in the lowest quartile): adjusted HR = 1.48, 95% confide ce interval (CI): 1.03–2.14 (Table 2). Notably, consistent with the fi ding in a prior study[12], the observed association was much stronger among participants whose MF exposure was measured on a typical day of the pregnancy (aHR = 2.72, 1.42–5.19). In contrast, there was no observed association among those whose MF was measured on a non-typical day (Table 2). Thus, the following analyses were restricted to those whose MF was measured on a typical day of their pregnancy.

Next, we examined the association separately among women with and without multiple prior miscarriages ($\geq$2). Table 3 showed that the association was largely similar between these two groups, with the association being slightly stronger among women without multiple prior miscarriages.

Table 4 shows the possible dose-response relationship by examining the association for each quartile using the lowest quartile (2.5 mG) as the reference group. While all higher quartiles showed an increased risk of miscarriage compared to the lowest MF exposure group, there was no dose-response relationship observed. These results are similar to those of a prior study[12].

The above-observed association was consistent regardless of the source of the MF. Although we did not have information on the exact sources from which MF was generated, based on participants' diary, we were able to examine whether MF exposure was from any of the following location categories: at home, at home in bed, at work, in transit, or from other sources. The association was observed consistently, regardless of the location. In addition to the adjusted variables mentioned above, further adjustment for nausea and vomiting as well as the following variables did not change the results in Tables 2–4: maternal income, marital status, maternal nausea/vomiting, alcohol use, caffeine intake, maternal fever, vaginal bleeding, urinary tract infection, carrying loads > 10 pounds, exposure to solvents or degreasers, vitamin intake, and Jacuzzi/hot tub/steam room/sauna use during pregnancy.

Discussion

After initial reports that provided evidence of an increased risk of miscarriage associated with high MF exposure during pregnancy[12,13], the current NIEHS-funded study provides additional evidence that exposure to high MF levels in pregnancy is associated with increased risk of miscarriage. Th s fi ding is also supported by four other studies published during the past 15 years that examined the relationship between high MF exposure and the risk of miscarriage[8–11,19]. Two of those studies measured EMF both inside, and in the surrounding areas, of the

Characteristic	Total N (N = 913)[a]	99th Percentile MF Level			
		Lowest quartile (N = 219)		Higher quartiles (N = 694)	
		N	%	N	%
Maternal age					
<30	296	61	*27.9%*	235	*33.9%*
30–34	288	71	*32.4%*	217	*31.3%*
≥35	329	87	*39.7%*	242	*34.9%*
Race					
White	326	91	*41.7%*	235	*34.0%*
Black	90	16	*7.3%*	74	*10.7%*
Hispanic	226	51	*23.4%*	175	*25.3%*
Asian /Pacific Islander	202	44	*20.2%*	158	*22.8%*
Other	66	16	*7.3%*	50	*7.2%*
Education					
<High school	42	5	*2.3%*	37	*5.4%*
High school or GED	142	32	*14.7%*	110	*15.9%*
Trade/Technical school	46	5	*2.3%*	41	*5.9%*
College degree	495	128	*58.7%*	367	*53.1%*
Graduate school	184	48	*22.0%*	136	*19.7%*
Marital Status					
Single	72	12	*5.5%*	60	*8.7%*
Partnered	147	31	*14.2%*	116	*16.8%*
Married	690	175	*80.3%*	515	*74.5%*
Worked in last year					
No	183	47	*21.6%*	136	*19.7%*
Yes	727	171	*78.4%*	556	*80.3%*
Smoked since LMP					
No	807	196	*91.2%*	611	*89.3%*
Yes	92	19	*8.8%*	73	*10.7%*
Coffee intake since LMP					
0 cup/day	637	142	*64.8%*	495	*71.3%*
0–1 cup/day	201	52	*23.7%*	149	*21.5%*
>1 cups/day	75	25	*11.4%*	50	*7.2%*
Alcohol use since LMP					
No	514	127	*58.3%*	387	*55.8%*
Yes	397	91	*41.7%*	306	*44.2%*
Number of previous pregnancies					
0	94	21	*9.6%*	73	*10.5%*
1	103	18	*8.2%*	85	*12.2%*
2	140	36	*16.4%*	104	*15.0%*
≥3	576	144	*65.8%*	432	*62.2%*
Number of previous miscarriages					
0	276	60	*27.4%*	216	*31.1%*
1	79	21	*9.6%*	58	*8.4%*
2	403	101	*46.1%*	302	*43.5%*
≥3	155	37	*16.9%*	118	*17.0%*
History of subfertility					
No	633	147	*67.1%*	486	*70.0%*
Yes	280	72	*32.9%*	208	*30.0%*
Vaginal bleeding since LMP					
No	670	165	*75.7%*	505	*72.9%*
Yes	241	53	*24.3%*	188	*27.1%*
Urinary tract infection since LMP					
No	860	211	*96.8%*	649	*93.9%*
Yes	49	7	*3.2%*	42	*6.1%*
Fever since LMP					
No	851	198	*92.1%*	653	*94.8%*

Continued

Characteristic	Total N (N = 913)[a]	99th Percentile MF Level			
		Lowest quartile (N = 219)		Higher quartiles (N = 694)	
		N	%	N	%
Yes	53	17	*7.9%*	36	*5.2%*
Carry loads (>10 pounds) since LMP					
No	416	92	*42.2%*	324	*46.8%*
Yes	494	126	*57.8%*	368	*53.2%*
Used Jacuzzi/hot tub/steam room/sauna since LMP					
No	807	200	*91.7%*	607	*87.7%*
Yes	103	18	*8.3%*	85	*12.3%*
Exposure to solvents or degreasers since LMP					
No	609	148	*68.5%*	461	*67.7%*
Yes	288	68	*31.5%*	220	*32.3%*
Vitamin use since LMP					
No	91	16	*7.3%*	75	*10.8%*
Yes	820	202	*92.7%*	618	*89.2%*
Gestational age at study entry					
0–48 days	763	173	*79.0%*	590	*85.0%*
49–69 days	135	41	*18.7%*	94	*13.5%*
≥70 days	15	5	*2.3%*	10	*1.4%*

Table 1. Characteristics of the Study Population by Daily Magnetic Field Exposure Level (Lowest or Higher Quartiles of MF 99th Percentile). Abbreviation: LMP, Last menstrual period. [a]The numbers in each individual category may not sum to the total number because of missing data.

99th Percentile MF Level	Total N	Miscarriage N (%)	cHR (95% CI)	aHR[a] (95% CI)
Among all participants				
Lowest quartile	219	36 (*16.4%*)	Ref	Ref
Higher quartiles	694	164 (*23.6%*)	1.43 (1.00–2.06)	1.48 (1.03–2.14)
MF measured on *typical days*				
Lowest quartile	106	11 (*10.4%*)	Ref	Ref
Higher quartiles	347	84 (*24.2%*)	2.46 (1.31–4.62)	**2.72** (1.42–5.19)
MF measured on non-typical days				
Lowest quartile	113	25 (*22.1%*)	Ref	Ref
Higher quartiles	347	80 (*23.1%*)	1.02 (0.65–1.62)	1.08 (0.67–1.73)

Table 2. Exposure to High Magnetic Fields (MFs) During Pregnancy and the Risk of Miscarriage. cHR: crude (unadjusted) hazard ratio; aHR: adjusted hazard ratio. 95% CI: 95% Confide ce interval. [a]Adjusted for maternal age at interview, race, education, smoking since LMP and prior miscarriage. Further adjustment for the following variables did not change the results: maternal nausea/vomiting, maternal income, marital status, alcohol use, caffeine intake, maternal fever, vaginal bleeding, urinary tract infection, carrying loads > 10lbs, exposure to solvents or degreasers, vitamin intake and Jacuzzi/hot tub/steam room/sauna use during pregnancy.

residence of participating pregnant women, and observed a higher risk of miscarriage associated with higher EMF exposure levels[8,9]. Two other studies examined the impact of EMF emitted from cell phones and wireless networks, and observed that more frequent cell phone use and close proximity to wireless base stations were both associated with an increased risk of miscarriage[10,11]. Although none of these studies conducted any personal MF measurements to capture actual MF exposure from all sources, as the current study has done, all four studies reported an increased risk of miscarriage associated with high MF exposure.

One of the most challenging aspects of assessing the health impact of MF exposure is the ability to measure MF exposure accurately as well as in the relevant etiological period. Prospectively measuring MF exposure in the etiologically relevant timeframe is essential and preferable to retrospective measurements. It is especially problematic to ascertain MF exposure long after the relevant window of exposure has passed. While logistically challenging, a prospective study design with a device that captures actual MF levels from all emitting sources in an etiologically relevant period will notably improve the accuracy of MF exposure assessment in epidemiological studies in a human population. In addition, as both this study and a previous study[12] demonstrated, even with a prospective design, if measurements were not conducted on a typical day to reflect true MF exposure during pregnancy, such study design could still fail to detect any MF health risk due to misclassifi ation of MF exposure (see Table 2). Therefore, to ensure accurate exposure assessment, MF measurements need to be conducted prospectively during an etiologically relevant window *and* to refl ct a participant's typical MF exposure patterns. The

99th Percentile MF Level	Total N	Miscarriage N (%)	cHR (95% CI)	aHR^{a} (95% CI)
≤1 prior miscarriages				
Lowest quartile	39	3 (*7.7%*)	Ref	Ref
Higher quartiles	143	27 (*18.9%*)	**2.69** (0.82–8.87)	**3.76** (1.07–13.18)
≥2 prior miscarriages				
Lowest quartile	67	8 (*11.9%*)	Ref	Ref
Higher quartiles	204	57 (*27.9%*)	**2.43** (1.16–5.11)	**2.56** (1.19–5.50)

Table 3. Exposure to High Magnetic Fields (MFs) During Pregnancy and the Risk of Miscarriage, Stratified by Number of Prior Miscarriages, *MF Measured on Typical Days Only*. cHR: crude (unadjusted) hazard ratio; aHR: adjusted hazard ratio. 95% CI: 95% Confidence interval. [a]Adjusted for maternal age at interview, race, education, smoking since LMP, and gravidity. Further adjustment for the following variables did not change the results: maternal nausea/vomiting, maternal income, marital status, alcohol use, caffeine intake, maternal fever, vaginal bleeding, urinary tract infection, carrying loads > 10lbs, exposure to solvents or degreasers, vitamin intake and Jacuzzi/hot tub/steam room/sauna use during pregnancy.

99th Percentile MF Level	Total N	Miscarriage N (%)	cHR (95% CI)	aHR^{a} (95% CI)
1st quartile (<2.5 mG)	106	11 (*10.4%*)	Ref	Ref
2nd quartile (2.5–3.6 mG)	116	32 (*27.6%*)	2.87 (1.45–5.70)	3.29 (1.59–6.79)
3rd quartile (3.7–6.2 mG)	119	31 (*26.1%*)	2.70 (1.36–5.39)	3.01 (1.48–6.12)
4th quartile (≥6.3 mG)	112	21 (*18.8%*)	1.83 (0.88–3.79)	2.02 (0.95–4.28)

Table 4. Exposure to High Magnetic Fields (MFs) During Pregnancy and the Risk of Miscarriage – Assessing Dose-Response, *MF Measured on Typical Days Only*. cHR: crude (unadjusted) hazard ratio; aHR: adjusted hazard ratio. 95% CI: 95% Confidence interval. [a]Adjusted for maternal age at interview, race, education, smoking since LMP, and prior miscarriage. Further adjustment for the following variables did not change the results: maternal nausea/vomiting, maternal income, marital status, alcohol use, caffeine intake, maternal fever, vaginal bleeding, urinary tract infection, carrying loads > 10lbs, exposure to solvents or degreasers, vitamin intake and Jacuzzi/hot tub/steam room/sauna use during pregnancy.

determination of whether the activity pattern was typical needs to be verified after measurement is complete since planned activities can change during the measurement day. It is clear that, if MF exposure is measured subjectively (e.g., interview based on participants' recall) or based on surrogate measures (e.g., wire codes, distance from power lines, job matrix, spot measurement at home, etc.), it would be very difficult for such studies to detect any MF health effect in epidemiological studies due to gross inaccuracies in measuring actual MF exposure levels. By definition, inaccurate MF measures lead to misclassification of MF exposure, which generally result in null findings. Unfortunately, the vast majority of epidemiological studies on MF health effects in the literature so far have been based on subjective and unreliable MF measurements. Thus, it is not surprising that many of the past studies failed to detect MF health effects. In addition, the focus on studying MF effects on cancer has exacerbated the problem, since the development of cancer usually has a long latency period between exposure and outcome that could span several decades. This has made accurately measure MF exposure in the etiologically relevant period (decades before the diagnosis of cancer) almost impossible. Those "null findings" have left a false impression of the "safety" of MF exposure.

The strength of this current study is that, in addition to using an objective measuring device (EMDEX Lite meter), we examined an outcome (miscarriage) with a short latency period (days or weeks rather than years or decades as in the case of cancers or autoimmune diseases). Thus, we were able to measure MF exposure prospectively in the relevant time period (during pregnancy). Furthermore, at the end of the measurement day, we ascertained whether activity patterns on that day reflected a typical day, which allowed us to identify participants with MF exposure measurements that more accurately reflected MF exposure during their pregnancies.

In this study, we found an almost three-fold increased risk of miscarriage if a pregnant woman was exposed to higher MF levels compared to women with lower MF exposure. The association was independent of any specific MF exposure sources or locations, thus removing the concern that other factors connected to the sources of the exposure might account for the observed associations. While nausea and vomiting were hypothesized to be potential confounders, adjustment for both nausea and vomiting did not change the results in this study or in a previous study[20]. Although we did not observe a dose-response relationship for MF exposure above 2.5 mG, this could be due to a threshold effect of MF exposure in which MF levels at or above 2.5 mG could lead to fetal demise, thus examining further higher levels of MF exposure were not able to confer additional risk.

Given the ubiquitous nature of exposure to this non-ionizing radiation, a small increased risk due to MF exposure could lead to unacceptable health consequences to pregnant women. Although the number of epidemiological studies examining the adverse impact of MF exposure in humans remains limited, the findings of this study should bring attention to this potentially important environmental hazard to pregnant women, at least in the context of miscarriage risk, and stimulate much needed additional research.

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Acknowledgements

Th s study was supported through funds provided by the *National Institute of Environmental Health Sciences* (*NIEHS*), Grant #5 R01 ES12226–5. Some of the results were presented at annual conferences of International Society of Environmental Epidemiology and Bioelectromagnetics Society 2015 and 2016.

Author Contributions

De-Kun Li conceived the concept, designed the study, obtained funding, oversaw the data gathering and analyses, and is responsible for the interpretation of results, and drafting and fi alizing the manuscript. Jeannette Ferber and Hong Chen were responsible for data management. Hong Chen was involved in data analysis and interpretation of the results. Roxana Odouli was involved in the study management and preparation of the manuscript. Charles Quesenberry was involved in interpretation of results and preparation of the manuscript. De-Kun Li is the guarantor of this paper who took full responsibility for the conduct of the study, had access to the data, and controlled the decision to publish.

Additional Information

Competing Interests: The authors declare that they have no competing interests.

EXHIBIT

25

Public Health Impacts
of
Wind Turbines

Prepared by:
Minnesota Department of Health
Environmental Health Division

In response to a request from:
Minnesota Department of Commerce
Office of Energy Security

May 22, 2009

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I. Introduction

In late February 2009 the Minnesota Department of Health (MDH) received a request from the Office of Energy Security (OES) in the Minnesota Department of Commerce, for a "white paper" evaluating possible health effects associated with low frequency vibrations and sound arising from large wind energy conversion systems (LWECS). The OES noted that there was a request for a Contested Case Hearing before the Minnesota Public Utilities Commission (PUC) on the proposed Bent Tree Wind Project in Freeborn County Minnesota; further, the OES had received a long comment letter from a citizen regarding a second project proposal, the Lakeswind Wind Power Plant in Clay, Becker and Ottertail Counties, Minnesota. This same commenter also wrote to the Commissioner of MDH to ask for an evaluation of health issues related to exposure to low frequency sound energy generated by wind turbines. The OES informed MDH that a white paper would have more general application and usefulness in guiding decision-making for future wind projects than a Contested Case Hearing on a particular project. (Note: A Contested Case Hearing is an evidentiary hearing before an Administrative Law Judge, and may be ordered by regulatory authorities, in this case the PUC, in order to make a determination on disputed issues of material fact. The OES advises the PUC on need and permitting issues related to large energy facilities.)

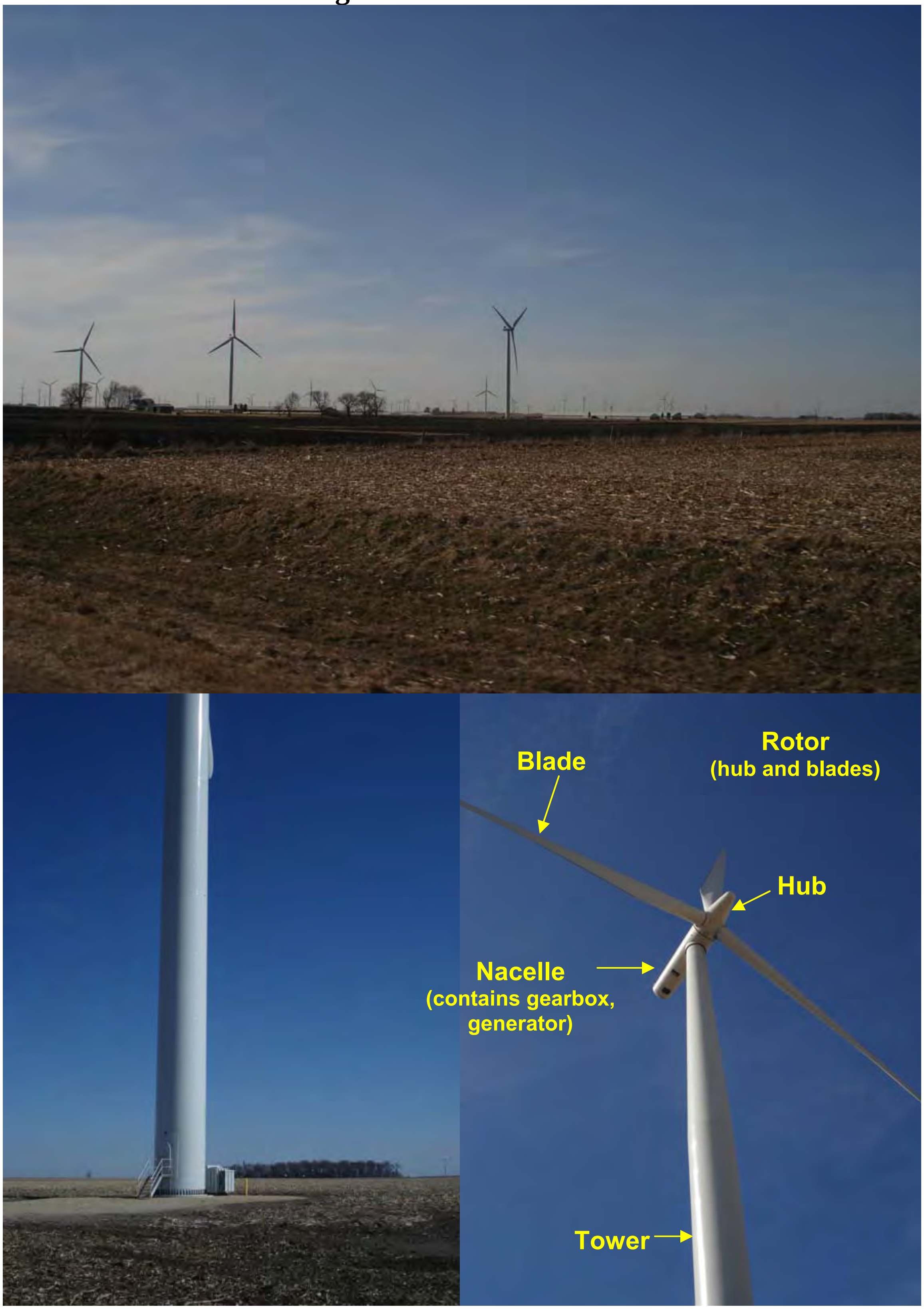
In early March 2009, MDH agreed to evaluate health impacts from wind turbine noise and low frequency vibrations. In discussion with OES, MDH also proposed to examine experiences and policies of other states and countries. MDH staff appeared at a hearing before the PUC on March 19, 2009, and explained the purpose and use of the health evaluation. The Commissioner replied to the citizen letter, affirming that MDH would perform the requested review.

A brief description of the two proposed wind power projects, and a brief discussion of health issues to be addressed in this report appear below.

A. Site Proposals

Wind turbines are huge and expensive machines requiring large capitol investment. Figure 1 shows some existing wind turbines in Minnesota. Large projects require control of extensive land area in order to optimize spacing of turbines to minimize turbulence at downwind turbines. Towers range up to 80 to 100 meters (260 to 325 feet), and blades can be up to 50 meters long (160 feet) (see Tetra Tech, 2008; WPL, 2008). Turbines are expected to be in place for 25-30 years.

Figure 1: Wind turbines



1. Bent Tree Wind Project in Freeborn County

This is a proposal by the Wisconsin Power and Light Company (WPL) for a 400 megawatt (MW) project in two phases of 200 MW each (requiring between 80 and 130 wind turbines). The cost of the first phase is estimated at $497 million. The project site area would occupy approximately 40 square miles located 4 miles north and west of the city of Albert Lea, approximately 95 miles south of Minneapolis (Figure 2) (WPL, 2008). The Project is a LWECS and a Certificate of Need (CON) from the PUC is required (*Minnesota Statutes 216B.243)*. The PUC uses the CON process to determine the basic type of facility (if any) to be constructed, the size of the facility, and when the project will be in service. The CON process involves a public hearing and preparation of an Environmental Report by the OES. The CON process generally takes a year, and is required before a facility can be permitted.

WPL is required to develop a site layout that optimizes wind resources. Accordingly, project developers are required to control areas at least 5 rotor diameters in the prevailing (north-south) wind directions (between about 1300 and 1700 feet for the 1.5 to 2.5 MW turbines under consideration for the project) and 3 rotor diameters in the crosswind (east-west) directions (between about 800 and 1000 feet). Thus, these are minimum setback distances from properties in the area for which easements have not been obtained. Further, noise rules promulgated by the Minnesota Pollution Control Agency (MPCA; *Minnesota Rules* Section 7030), specify a maximum nighttime noise in residential areas of 50 A-weighted decibels (dB(A). WPL has proposed a minimum setback of 1,000 feet from occupied structures in order to comply with the noise rule.

2. Noble Flat Hill Wind Park in Clay, Becker and Ottertail Counties

This is a LWECS proposed by Noble Flat Hill Windpark I (Noble), a subsidiary of Noble Environmental Power, based in Connecticut. The proposal is for a 201 MW project located 12 miles east of the City of Moorhead, about 230 miles northwest of Minneapolis (Figure 3) (Tetra Tech, 2008). The cost of the project is estimated to be between $382 million and $442 million. One hundred thirty-four GE 1.5 MW wind turbines are planned for an area of 11,000 acres (about 17 square miles); the site boundary encompasses approximately 20,000 acres. Setback distances of a minimum of 700 feet are planned to comply with the 50 dB(A) noise limit. However, rotor diameters will be 77 meters (250 feet). Therefore, setback distances in the prevailing wind direction of 1,300 feet are planned for properties where owners have not granted easements. Setbacks of 800 feet are planned in the crosswind direction.

Figure 2: Bent Tree Wind Project, Freeborn County

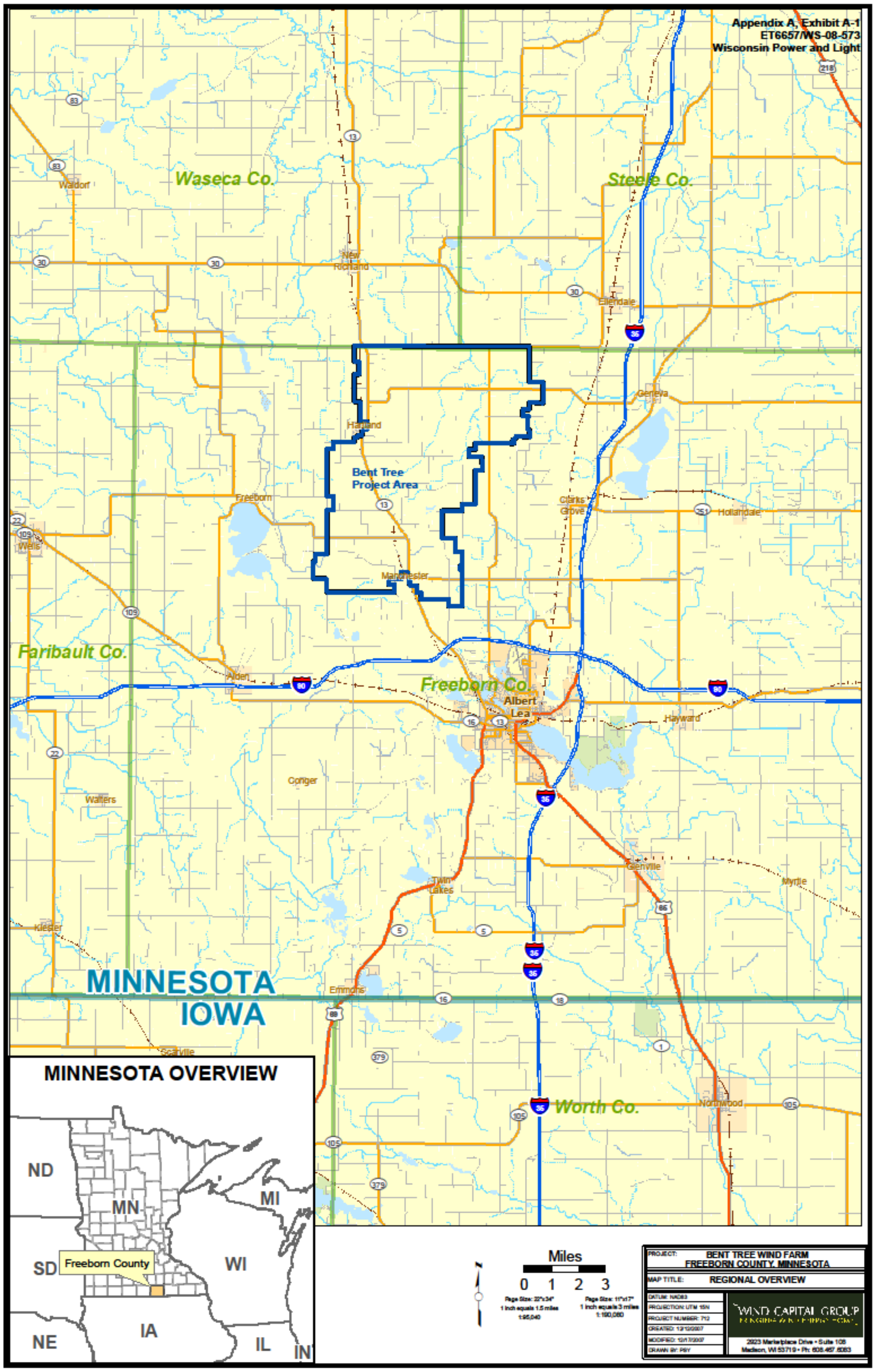
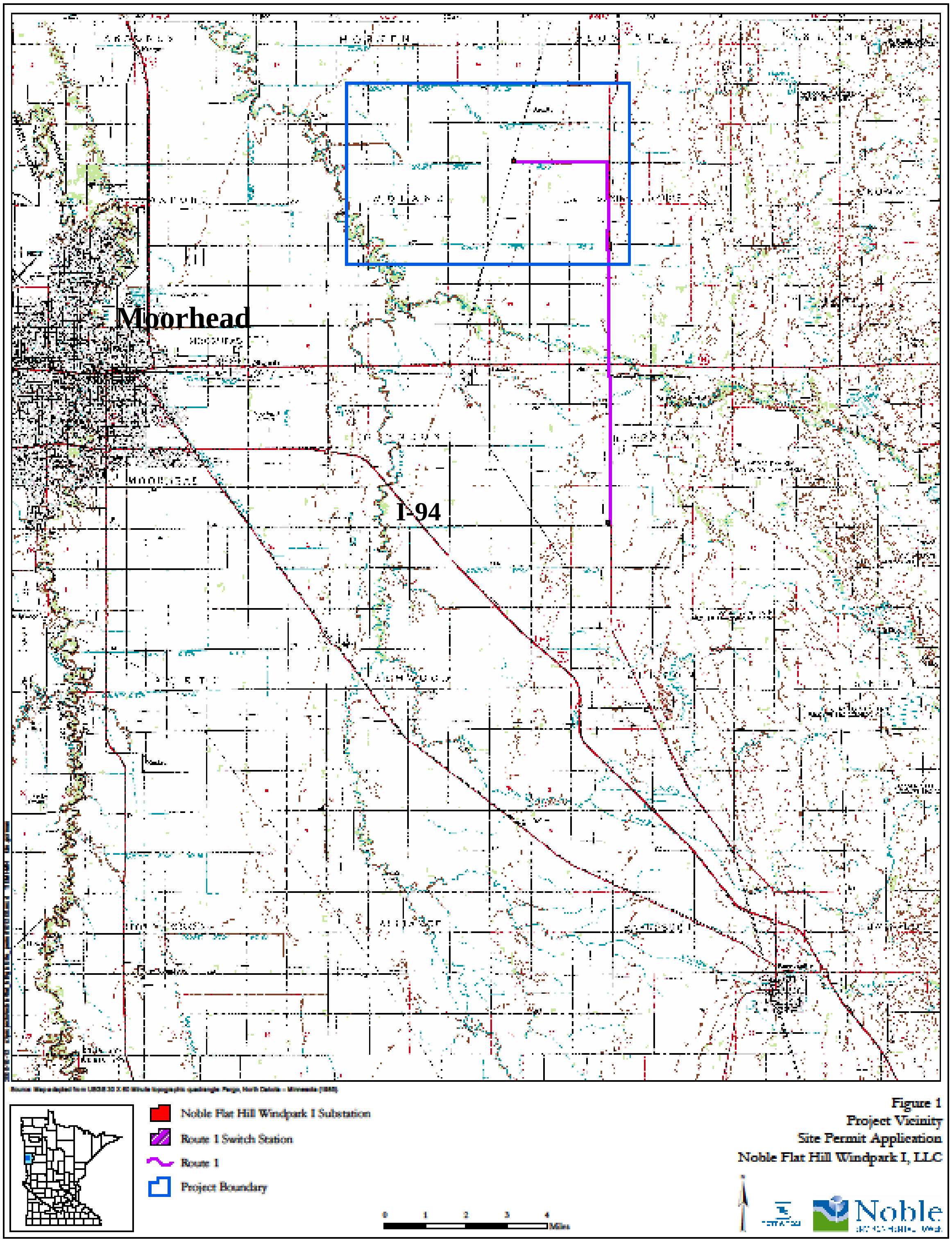


Figure 3: Noble Flat Hill Wind Park, Clay, Becker, Ottertail Counties



B. Health Issues

The National Research Council of the National Academies (NRC, 2007) has reviewed impacts of wind energy projects on human health and well-being. The NRC begins by observing that wind projects, just as other projects, create benefits and burdens, and that concern about impacts is natural when the source is near one's home. Further, the NRC notes that different people have different values and levels of sensitivity. Impacts noted by the NRC that may have the most effect on health include noise and low frequency vibration, and shadow flicker. While noise and vibration are the main focus of this paper, shadow flicker (casting of moving shadows on the ground as wind turbine blades rotate) will also be briefly discussed.

Noise originates from mechanical equipment inside the nacelles of the turbines (gears, generators, etc.) and from interaction of turbine blades with wind. Newer wind turbines generate minimal noise from mechanical equipment. The most problematic wind turbine noise is a broadband "whooshing" sound produced by interaction of turbine blades with the wind. Newer turbines have upwind rotor blades, minimizing low frequency "infrasound" (i.e., air pressure changes at frequencies below 20-100 Hz that are inaudible). However, the NRC notes that during quiet conditions at night, low frequency modulation of higher frequency sounds, such as are produced by turbine blades, is possible. The NRC also notes that effects of low frequency (infrasound) vibration (less than 20 Hz) on humans are not well understood, but have been asserted to disturb some people.

Finally, the NRC concludes that noise produced by wind turbines is generally not a major concern beyond a half mile. Issues raised by the NRC report and factors that may affect distances within which wind turbine noise may be problematic are discussed more extensively below.

II. Elementary Characteristics of Sensory Systems and Sound

A. Sensory Systems

1. Hearing

Sensory systems respond to a huge dynamic range of physical stimuli within a relatively narrow dynamic range of mechanical, chemical and/or neuronal (electrophysiological) output. Compression of the dynamic range is accomplished by systems that respond to logarithmic increases in intensity of physical stimuli with arithmetically increasing sensory responses. This general property is true for hearing, and has been recognized since at least the mid-19th century (see e.g., Woodworth and Schlosberg, 1964). "Loudness" is the sensory/perceptual correlate of the physical intensity of air pressure changes to which the electro-mechanical transducers in the ear and associated neuronal pathways are sensitive. Loudness increases as the logarithm of air pressure, and it is convenient to relate loudness to a reference air pressure (in dyne/cm^2 or pascals) in tenths of logarithmic units (decibels; dB). Further, the ear is sensitive to only a relatively narrow frequency range of air pressure changes: those between approximately 20 and 20,000 cycles per second or Herz (Hz). In fact, sensitivity varies within this range, so that the sound pressure level relative to a reference value that is audible in the middle of the range (near 1,000 Hz) is about 4 orders of magnitude smaller than it is at 20 Hz and about 2 orders of magnitude smaller than at 20,000 Hz (Fig. 3). Accordingly, measurements of loudness in dB generally employ filters to equalize the loudness of sounds at different frequencies or "pitch." To approximate the sensitivity of the ear, A-weighted filters weigh sound pressure changes at frequencies in the mid-range more than those at higher or lower frequencies. When an A-weighted filter is used, loudness is measured in dB(A). This is explained in greater detail in Section B below.

The ear accomplishes transduction of sound through a series of complex mechanisms (Guyton, 1991). Briefly, sound waves move the eardrum (tympanic membrane), which is in turn connected to 2 small bones (ossicles) in the middle ear (the malleus and incus). A muscle connected to the malleus keeps the tympanic membrane tensed, allowing efficient transmission to the malleus of vibrations on the membrane. Ossicle muscles can also relax tension and attenuate transmission. Relaxation of muscle tension on the tympanic membrane protects the ear from very loud sounds and also masks low frequency sounds, or much background noise. The malleus and incus move a third bone (stapes). The stapes in turn applies pressure to the fluid of the cochlea, a snail-shaped structure imbedded in temporal bone. The cochlea is a complex structure, but for present purposes it is sufficient to note that pressure changes or waves of different frequencies in cochlear fluid result in bending of specialized hair cells in regions of the cochlea most sensitive to different frequencies or pitch. Hair cells are directly connected to nerve fibers in the vestibulocochlear nerve (VIII cranial nerve).

Transmission of sound can also occur directly through bone to the cochlea. This is a very inefficient means of sound transmission, unless a device (e.g. a tuning fork or hearing aid) is directly applied to bone (Guyton, 1991).

2. Vestibular System

The vestibular system reacts to changes in head and body orientation in space, and is necessary for maintenance of equilibrium and postural reflexes, for performance of rapid and intricate body movements, and for stabilizing visual images (via the vestibulo-ocular reflex) as the direction of movement changes (Guyton, 1991).

The vestibular apparatus, like the cochlea, is imbedded in temporal bone, and also like the cochlea, hair cells, bathed in vestibular gels, react to pressure changes and transmit signals to nerve fibers in the vestibulocochlear nerve. Two organs, the utricle and saccule, called otolith organs, integrate information about the orientation of the head with respect to gravity. Otoliths are tiny stone-like crystals, embedded in the gels of the utricle and saccule, that float as the head changes position within the gravitational field. This movement is translated to hair cells. Three semi-circular canals, oriented at right angles to each other, detect head rotation. Stimulation of the vestibular apparatus is not directly detected, but results in activation of motor reflexes as noted above (Guyton, 1991).

Like the cochlea, the vestibular apparatus reacts to pressure changes at a range of frequencies; optimal frequencies are lower than for hearing. These pressure changes can be caused by body movements, or by direct bone conduction (as for hearing, above) when vibration is applied directly to the temporal bone (Todd et al., 2008). These investigators found maximal sensitivity at 100 Hz, with some sensitivity down to 12.5 Hz. The saccule, located in temporal bone just under the footplate of the stapes, is the most sound-sensitive of the vestibular organs (Halmagyi et al., 2004). It is known that brief loud clicks (90-95 dB) are detected by the vestibular system, even in deaf people. However, we do not know what the sensitivity of this system is through the entire range of sound stimuli.

While vestibular system activation is not directly felt, activation may give rise to a variety of sensations: vertigo, as the eye muscles make compensatory adjustments to rapid angular motion, and a variety of unpleasant sensations related to internal organs. In fact, the vestibular system interacts extensively with the "autonomic" nervous system, which regulates internal body organs (Balaban and Yates, 2004). Sensations and effects correlated with intense vestibular activation include nausea and vomiting and cardiac arrhythmia, blood pressure changes and breathing changes.

While these effects are induced by relatively intense stimulation, it is also true that A-weighted sound measurements attuned to auditory sensitivity, will underweight low frequencies for which the vestibular system is much more sensitive (Todd et al., 2008). Nevertheless, activation of the vestibular system *per se* obviously need not give rise to unpleasant sensations. It is not known what stimulus intensities are generally required for for autonomic activation at relatively low frequencies, and it is likely that there is considerable human variability and capacity to adapt to vestibular challenges.

B. Sound

1. Introduction

Sound is carried through air in compression waves of measurable frequency and amplitude. Sound can be tonal, predominating at a few frequencies, or it can contain a random mix of a broad range of frequencies and lack any tonal quality (white noise). Sound that is unwanted is called noise.

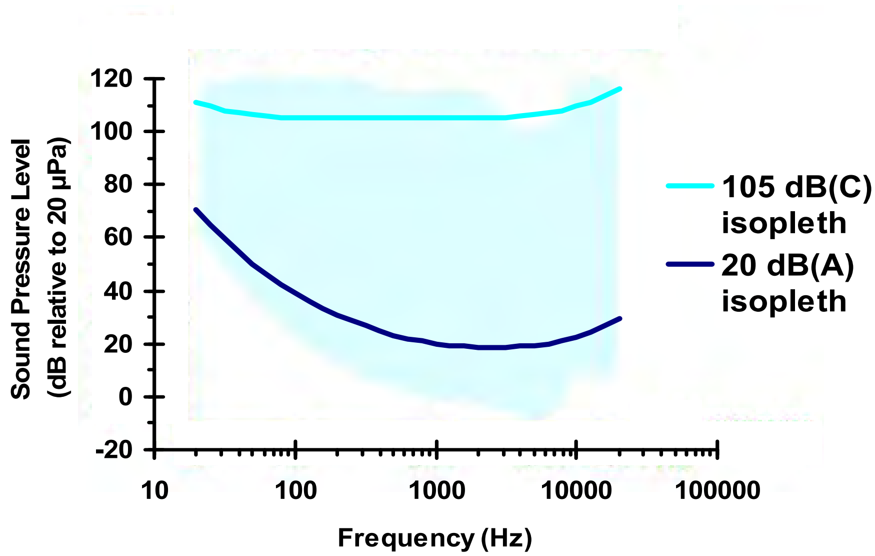
Audible Frequency Sound

Besides frequency sensitivity (between 20 and 20,000 Hz), humans are also sensitive to changes in the amplitude of the signal (compression waves) within this audible range of frequencies. Increasing amplitude, or increasing sound pressure, is perceived as increasing volume or loudness. The sound pressure level in air (SPL) is measured in micro Pascals (µPa). SPLs are typically converted in measuring instruments and reported as decibels (dB) which is a log scale, relative unit (see above). When used as the unit for sound, dBs are reported relative to a SPL of 20 µPa. Twenty µPa is used because it is the approximate threshold of human hearing sensitivity at about 1000 Hz. Decibels relative to 20 µPa are calculated from the following equation:

$$\text{Loudness (dB)} = \text{Log}((\text{SPL} / 20\ \mu\text{Pa})^2) * 10$$

Figure 4 shows the audible range of normal human hearing. Note that while the threshold sensitivity varies over the frequency range, at high SPLs sensitivity is relatively consistent over audible frequencies.

Figure 4: Audible Range of Human Hearing



Equivalence curves for different frequencies, when sound meter readings in dB are taken with A or C-weighting filters. (Adapted from EPD Hong Kong SAR, 2009)

Sub-Audible Frequency Sound

Sub-audible frequency sound is often called infrasound. It may be sensed by people, similar to audible sound, in the cochlear apparatus in the ear; it may be sensed by the vestibular system which is responsible for balance and physical equilibrium; or it may be sensed as vibration.

Resonance and modulation

Sound can be attenuated as it passes through a physical structure. However, because the wavelength of low frequency sound is very long (the wavelength of 40 Hz in air at sea level and room temperature is 8.6 meters or 28 ft), low frequencies are not effectively attenuated by walls and windows of most homes or vehicles. (For example, one can typically hear the bass, low frequency music from a neighboring car at a stoplight, but not the higher frequencies.) In fact, it is possible that there are rooms within buildings exposed to low frequency sound or noise where some frequencies may be amplified by resonance (e.g. ½ wavelength, ¼ wavelength) within the structure. In addition, low frequency sound can cause vibrations within a building at higher, more audible frequencies as well as throbbing or rumbling.

Sounds that we hear generally are a mixture of different frequencies. In most instances these frequencies are added together. However, if the source of the sound is not constant, but changes over time, the effect can be re-occurring pulses of sound or low frequency modulation of sound. This is the type of sound that occurs from a steam engine, a jack hammer, music and motor vehicle traffic. Rhythmic, low frequency pulsing of higher frequency noise (like the sound of an amplified heart beat) is one type of sound that can be caused by wind turbine blades under some conditions.

2. Human Response to Low Frequency Stimulation

There is no consensus whether sensitivity below 20 Hz is by a similar or different mechanism than sensitivity and hearing above 20 Hz (Reviewed by Møller and Pedersen, 2004). Possible mechanisms of sensation caused by low frequencies include bone conduction at the applied frequencies, as well as amplification of the base frequency and/or harmonics by the auditory apparatus (eardrum and ossicles) in the ear. Sensory thresholds are relatively continuous, suggesting (but not proving) a similar mechanism above and below 20 Hz. However, it is clear that cochlear sensitivity to infrasound (< 20 Hz) is considerably less than cochlear sensitivity to audible frequencies.

Møller and Pedersen (2004) reviewed human sensitivity at low and infrasonic frequencies. The following findings are of interest:

- When whole-body pressure-field sensitivity is compared with ear-only (earphone) sensitivity, the results are very similar. These data suggest that the threshold sensitivity for low frequency is through the ear and not vestibular.
- Some individuals have extraordinary sensitivity at low frequencies, up to 25 dB more sensitive than the presumed thresholds at some low frequencies.
- While population average sensitivity over the low frequency range is smooth, sound pressure thresholds of response for individuals do not vary smoothly but are inconsistent, with peaks and valleys or "microstructures". Therefore the sensitivity response of individuals to different low frequency stimulation may be difficult to predict.
- Studies of equal-loudness-levels demonstrate that as stimulus frequency decreases through the low frequencies, equal-loudness lines compress in the dB scale. (See Figure 4 as an example of the relatively small difference in auditory SPL range between soft and loud sound at low frequencies).
- The hearing threshold for pure tones is different than the hearing threshold for white noise at the same total sound pressure.

3. Sound Measurements

Sound measurements are taken by instruments that record sound pressure or the pressure of the compression wave in the air. Because the loudness of a sound to people is usually the primary interest in measuring sound, normalization schemes or filters have been applied to absolute measurements. dB(A) scaling of sound pressure measurements was intended to normalize readings to equal loudness over the audible range of frequencies at low loudness. For example, a 5,000 Hz (5 kHz) and 20 dB(A) tone is expected to have the same intensity or loudness as a 100 Hz, 20 dB(A) tone. However, note that the absolute sound pressures would be about 200 μPa and 2000 μPa, respectively, or about a difference of 20 dB (relative to 20 μPa), or as it is sometimes written 20 dB(linear).

Most sound is not a single tone, but is a mixture of frequencies within the audible range. A sound meter can add the total SPLs for all frequencies; in other words, the dB readings over the entire spectrum of audible sound can be added to give a single loudness metric. If sound is reported as A-weighted, or dB(A), it is a summation of the dB(A) scaled sound pressure from 20 Hz to 20 kHz.

In conjunction with the dB(A) scale, the dB(B) scale was developed to approximate equal loudness to people across audible frequencies at medium loudness, and dB(C) was developed to approximate equal-loudness for loud environments. Figure 4 shows isopleths for 20 dB(A) and 105 dB(C). While dB(A), dB(B), dB(C) were developed from empirical data at the middle frequencies, at the ends of the curves these scales were extrapolated, or sketched in, and are not based on experimental or observational data (Berglund et al., 1996). As a result, data in the low frequency range (and probably the highest audible frequencies as well) cannot be reliably interpreted using these scales. The World Health Organization (WHO, 1999) suggests that A-weighting noise that has a large low frequency component is not reliable assessment of loudness.

The source of the noise, or the noise signature, may be important in developing equal-loudness schemes at low frequencies. C-weighting has been recommended for artillery noise, but a linear, unweighted scale may be even better at predicting a reaction (Berglund et al., 1996). A linear or equal energy rating also appears to be the most effective predictor of reaction to low frequency noise in other situations, including blast noise from mining. The implication of the analysis presented by Berglund et al. (1996) is that annoyance from non-tonal noise should not be estimated from a dB(A) scale, but may be better evaluated using dB(C), or a linear non-transformed scale.

However, as will be discussed below, a number of schemes use a modified dB(A) scale to evaluate low frequency noise. These schemes differ from a typical use of the dB(A) scale by addressing a limited frequency range below 250 Hz, where auditory sensitivity is rapidly changing as a function of frequency (see Figure 4).

III. Exposures of Interest

A. Noise From Wind Turbines

1. Mechanical noise

Mechanical noise from a wind turbine is sound that originates in the generator, gearbox, yaw motors (that intermittently turn the nacelle and blades to face the wind), tower ventilation system and transformer. Generally, these sounds are controlled in newer wind turbines so that they are a fraction of the aerodynamic noise. Mechanical noise from the turbine or gearbox should only be heard above aerodynamic noise when they are not functioning properly.

2. Aerodynamic noise

Aerodynamic noise is caused by wind passing over the blade of the wind turbine. The tip of a 40-50 meter blade travels at speeds of over 140 miles per hour under normal operating conditions. As the wind passes over the moving blade, the blade interrupts the laminar flow of air, causing turbulence and noise. Current blade designs minimize the amount of turbulence and noise caused by wind, but it is not possible to eliminate turbulence or noise.

Aerodynamic noise from a wind turbine may be underestimated during planning. One source of error is that most meteorological wind speed measurements noted in wind farm literature are taken at 10 meters above the ground. Wind speed above this elevation, in the area of the wind turbine rotor, is then calculated using established modeling relationships. In one study (van den Berg, 2004) it was determined that the wind speeds at the hub at night were up to 2.6 times higher than modeled. Subsequently, it was found that noise levels were 15 dB higher than anticipated.

Unexpectedly high aerodynamic noise can also be caused by improper blade angle or improper alignment of the rotor to the wind. These are correctable and are usually adjusted during the turbine break-in period.

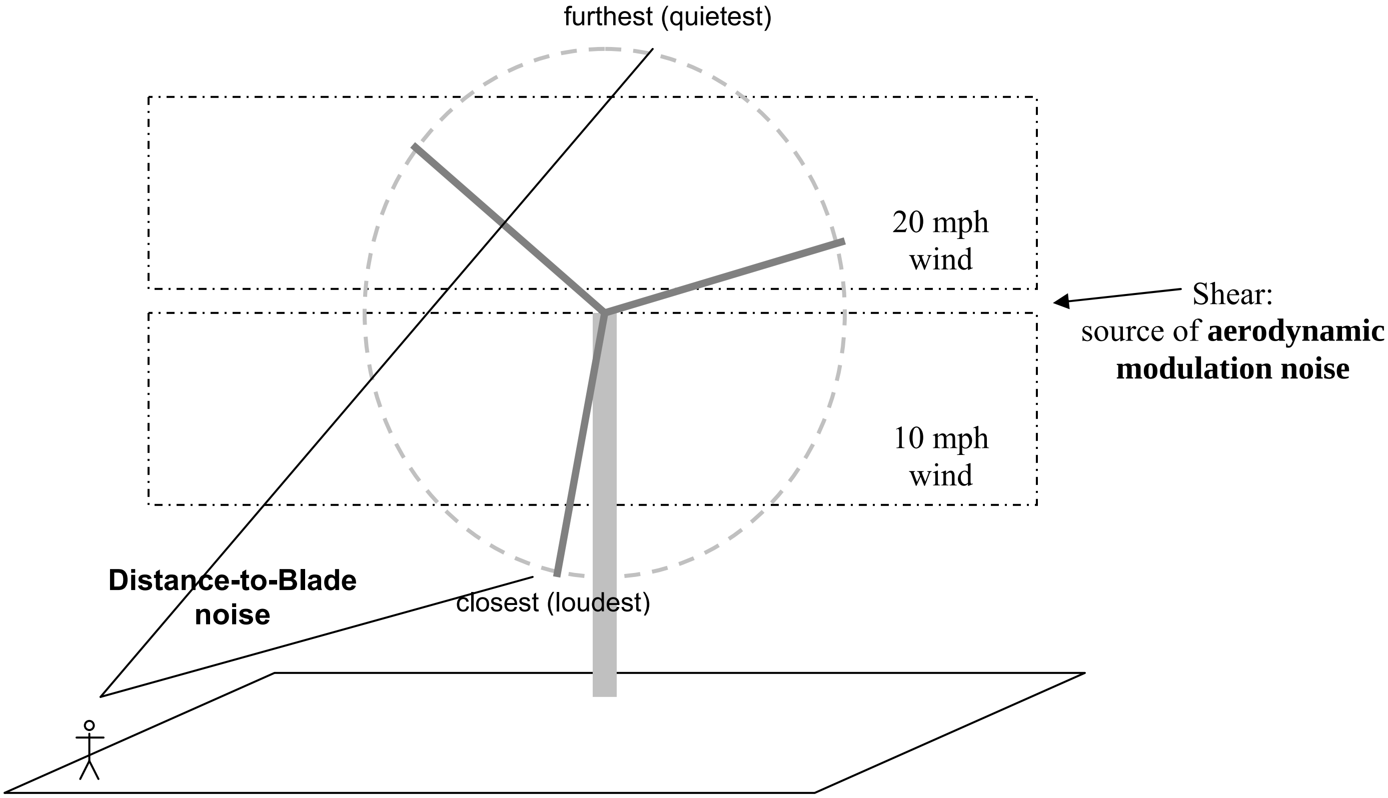
3. Modulation of aerodynamic noise

Rhythmic modulation of noise, especially low frequency noise, has been found to be more annoying than steady noise (Bradley, 1994; Holmberg et al., 1997). One form of rhythmic modulation of aerodynamic noise that can be noticeable very near to a wind turbine is a distance-to-blade effect. To a receptor on the ground in front of the wind turbine, the detected blade noise is loudest as the blade passes, and quietest when the blade is at the top of its rotation. For a modern 3-blade turbine, this distance-to-blade effect can cause a pulsing of the blade noise at about once per second (1 Hz). On the ground, about 500 feet directly downwind from the turbine, the distance-to-blade can cause a difference in sound pressure of about 2 dB between the *tip* of the blade at its farthest point and the *tip* of the blade at its nearest point (48 meter blades, 70 meter tower). Figure 5 demonstrates why the loudness of blade noise (aerodynamic noise) pulses as the distance-to-blade varies for individuals close to a turbine.

If the receptor is 500 feet from the turbine base, in line with the blade rotation or up to 60° off line, the difference in sound pressure from the *tip* of the blade at its farthest and nearest point can be about 4-5 dB, an audible difference. The tip travels faster than the rest of the blade and is closer to (and then farther away from) the receptor than other parts of the blade. As a result, noise from other parts of the blade will be modulated less than noise from the tip. Further, blade design can also affect the noise signature of a blade. The distance-to-blade effect diminishes as receptor distance increases because the relative difference in distance from the receptor to the top or to the bottom of the blade becomes smaller. Thus, moving away from the tower, distance-to-blade noise gradually appears to be more steady.

Another source of rhythmic modulation may occur if the wind through the rotor is not uniform. Blade angle, or pitch, is adjusted for different wind speeds to maximize power and to minimize noise. A blade angle that is not properly tuned to the wind speed (or wind direction) will make more noise than a properly tuned blade. Horizontal layers with different wind speeds or directions can form in the atmosphere. This wind condition is called shear. If the winds at the top and bottom of the blade rotation are different, blade noise will vary between the top and bottom of blade rotation, causing modulation of aerodynamic noise. This noise, associated with the blades passing through areas of different air-wind speeds, has been called aerodynamic modulation and is demonstrated in Figure 5.

Figure 5: Sources of noise modulation or pulsing



In some terrains and under some atmospheric conditions wind aloft, near the top of the wind turbine, can be moving faster than wind near the ground. Wind turbulence or even wakes from adjacent turbines can create non-uniform wind conditions as well. As a result of aerodynamic modulation a rhythmic noise pattern or pulsing will occur as each blade passes through areas with different wind speed. Furthermore, additional noise, or thumping, may occur as each blade passes through the transition between different wind speed (or wind direction) areas.

Wind shear caused by terrain or structures on the ground (e.g. trees, buildings) can be modeled relatively easily. Wind shear in areas of flat terrain is not as easily understood. During the daytime wind in the lower atmosphere is strongly affected by thermal convection which causes mixing of layers. Distinct layers do not easily form. However, in the nighttime the atmosphere can stabilize (vertically), and layers form. A paper by G.P. van den Berg (2008) included data from a study on wind shear at Cabauw, The Netherlands (flat terrain). Annual average wind speeds at different elevations above ground was reported. The annual average wind speed at noon was about 5.75 meters per second (m/s; approximately 12.9 miles per hour(mph)) at 20 m above ground, and about 7.6 m/s (17 mph) at 140 m. At midnight, the annual averages were about 4.3 m/s (9.6 mph) and 8.8 m/s (19.7 mph) for 20m and 140 m, respectively, above ground. The data show that while the average windspeed (between 20m and 140m) is very similar at noon and midnight at Cabauw, the windspeed difference between elevations during the day is much less than the difference at night (1.85 m/s (4.1 mph) and 4.5 m/s (10 mph), respectively). As a result one would expect that the blade angle can be better tuned to the wind speed during the daytime. Consequently, blade noise would be greater at night.

A number of reports have included discussion of aerodynamic modulation (van den Berg, 2005; UK Department of Transport and Industry, 2006; UK Department for Business Enterprise and Regulatory Reform, 2007; van den Berg, 2008). They suggest that aerodynamic modulation is typically underestimated when noise estimates are calculated. In addition, they suggest that detailed modeling of wind, terrain, land use and structures may be used to predict whether modulation of aerodynamic noise will be a problem at a proposed wind turbine site.

4. Wind farm noise

The noise from multiple turbines similarly distant from a residence can be noticeably louder than a lone turbine simply through the addition of multiple noise sources. Under steady wind conditions noise from a wind turbine farm may be greater than noise from the nearest turbine due to synchrony between noise from more than one turbine (van den Berg, 2005). Furthermore, if the dominant frequencies (including aerodynamic modulation) of different turbines vary by small amounts, an audible beat or dissonance may be heard when wind conditions are stable.

B. Shadow Flicker

Rhythmic light flicker from the blades of a wind turbine casting intermittent shadows has been reported to be annoying in many locations (NRC, 2007; Large Wind Turbine Citizens Committee, 2008). (Note: Flashing light at frequencies around 1 Hz is too slow to trigger an epileptic response.)

Modeling conducted by the Minnesota Department of Health suggests that a receptor 300 meters perpendicular to, and in the shadow of the blades of a wind turbine, can be in the flicker shadow of the rotating blade for almost 1½ hour a day. At this distance a blade may completely obscure the sun each time it passes between the receptor and the sun. With current wind turbine designs, flicker should not be an issue at distances over 10 rotational diameters (~1000 meters or 1 km (0.6 mi) for most current wind turbines). This distance has been recommended by the Wind Energy Handbook (Burton et al., 2001) as a minimum setback distance in directions that flicker may occur, and has been noted in the Bent Tree Permit Application (WPL, 2008).

Shadow flicker is a potential issue in the mornings and evenings, when turbine noise may be masked by ambient sounds. While low frequency noise is typically an issue indoors, shadow flicker can be an issue both indoors and outdoors when the sun is low in the sky. Therefore, shadow flicker may be an issue in locations other than the home.

Ireland recommends wind turbines setbacks of at least 300 meters from a road to decrease driver distraction (Michigan State University, 2004). The NRC (2007) recommends that shadow flicker is addressed during the preliminary planning stages of a wind turbine project.

IV. Impacts of Wind Turbine Noise

A. Potential Adverse Reaction to Sound

Human sensitivity to sound, especially to low frequency sound, is variable. Individuals have different ranges of frequency sensitivity to audible sound; different thresholds for each frequency of audible sound; different vestibular sensitivities and reactions to vestibular activation; and different sensitivity to vibration.

Further, sounds, such as repetitive but low intensity noise, can evoke different responses from individuals. People will exhibit variable levels of annoyance and tolerance for different frequencies. Some people can dismiss and ignore the signal, while for others, the signal will grow and become more apparent and unpleasant over time (Moreira and Bryan, 1972; Bryan and Tempest, 1973). These reactions may have little relationship to will or intent, and more to do with previous exposure history and personality.

Stress and annoyance from noise often do not correlate with loudness. This may suggest, in some circumstances, other factors impact an individual's reaction to noise. A number of reports, cited in Staples (1997), suggest that individuals with an interest in a project and individuals who have some control over an environmental noise are less likely to find a noise annoying or stressful.

Berglund et al. (1996) reviewed reported health effects from low frequency noise. Loud noise from any source can interfere with verbal communication and possibly with the development of language skills. Noise may also impact mental health. However, there are no studies that have looked specifically at the impact of low frequency noise on communication, development of language skills and mental health. Cardiovascular and endocrine effects have been demonstrated in studies that have looked at exposures to airplane and highway noise. In addition, possible effects of noise on performance and cognition have also been investigated, but these health studies have not generally looked at impacts specifically from low frequency noise. Noise has also been shown to impact sleep and sleep patterns, and one study demonstrated impacts from low frequency noise in the range of 72 to 85 dB(A) on chronic insomnia (Nagai et al., 1989 as reported in Berglund et al., 1996).

Case studies have suggested that health can be impacted by relatively low levels of low frequency noise. But it is difficult to draw general conclusions from case studies. Feldmann and Pitten (2004)) describe a family exposed during the winter to low frequency noise from a nearby heating plant. Reported health impacts were: "indisposition, decrease in performance, sleep disturbance, headache, ear pressure, crawl parästhesy [crawling, tingling or numbness sensation on the skin] or shortness of breath."

Annoyance, unpleasant sounds, and complaints

Reported health effects from low frequency stimulation are closely associated with annoyance from audible noise. "There is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects" (WHO, 1999). It has not been shown whether annoyance is a symptom or an accessory in the causation of health impacts from low frequency noise. Studies have been conducted on some aspects of low frequency noise that can cause annoyance.

Noise complaints are usually a reasonable measure of annoyance with low frequency environmental noise. Leventhall (2004) has reviewed noise complaints and offers the following conclusions:

> “ The problems arose in quiet rural or suburban environments
> The noise was often close to inaudibility and heard by a minority of people
> The noise was typically audible indoors and not outdoors
> The noise was more audible at night than day
> The noise had a throb or rumble characteristic
> The main complaints came from the 55-70 years age group
> The complainants had normal hearing.
> Medical examination excluded tinnitus.
>
> “ These are now recognised as classic descriptors of low frequency noise problems.”

These observations are consistent with what we know about the propagation of low intensity, low frequency noise. Some people are more sensitive to low frequency noise. The difference, in dB, between soft (acceptable) and loud (annoying) noise is much less at low frequency (see Figure 4 audible range compression). Furthermore, during the daytime, and especially outdoors, annoying low frequency noise can be masked by high frequency noise.

The observation that “the noise was typically audible indoors and not outdoors” is not particularly intuitive. However, as noted in a previous section, low frequencies are not well attenuated when they pass through walls and windows. Higher frequencies (especially above 1000 Hz) can be efficiently attenuated by walls and windows. In addition, low frequency sounds may be amplified by resonance within rooms and halls of a building. Resonance is often characterized by a throbbing or a rumbling, which has also been associated with many low frequency noise complaints.

Low frequency noise, unlike higher frequency noise, can also be accompanied by shaking, vibration and rattling. In addition, throbbing and rumbling may be apparent in some low frequency noise. While these noise features may not be easily characterized, numerous studies have shown that their presence dramatically lowers tolerance for low frequency noise (Berglund et al., 1996).

As reviewed in Leventhall (2003), a study of industrial exposure to low frequency noise found that fluctuations in total noise averaged over 0.5, 1.0 and 2.0 seconds correlated with annoyance (Holmberg et al., 1997). This association was noted elsewhere and led (Broner and Leventhall, 1983) to propose a 3dB “penalty” be added to evaluations of annoyance in cases where low frequency noise fluctuated.

In another laboratory study with test subjects controlling loudness, 0.5 – 4 Hz modulation of low frequency noise was found to be more annoying than non-modulated low frequency noise. On average test subjects found modulated noise to be similarly annoying as a constant tone 12.9 dB louder (Bradley, 1994).

B. Studies of Wind Turbine Noise Impacts on People

1. Swedish Studies

Two studies in Sweden collected information by questionnaires from 341 and 754 individuals (representing response rates of 68% and 58%, respectively), and correlated responses to calculated exposure to noise from wind farms (Pedersen and Waye, 2004; Pedersen, 2007; Pedersen and Persson, 2007). Both studies showed that the number of respondents perceiving the noise from the wind turbines increased as the calculated noise levels at their homes increased from less than 32.5 dB(A) to greater than 40 dB(A). Annoyance appeared to correlate or trend with calculated noise levels. Combining the data from the two studies, when noise measurements were greater than 40 dB(A), about 50% of the people surveyed (22 of 45 people) reported annoyance. When noise measurements were between 35 and 40 dB(A) about 24% reported annoyance (67 of 276 people). Noise annoyance was more likely in areas that were rated as quiet and in areas where turbines were visible. In one of the studies, 64% respondents who reported noise annoyance also reported sleep disturbance; 15% of respondents reported sleep disturbance without annoyance.

2. United Kingdom Study

Moorhouse et al. (UK Department for Business Enterprise and Regulatory Reform, 2007) evaluated complaints about wind farms. They found that 27 of 133 operating wind farms in the UK received formal complaints between 1991 and 2007. There were a total of 53 complainants for 16 of the sites for which good records were available. The authors of the report considered that many complaints in the early years were for generator and gearbox noise. However, subjective analyses of reports about noise ("like a train that never gets there", "distant helicopter", "thumping", "thudding", "pulsating", "thumping", "rhythmical beating", and "beating") suggested that aerodynamic modulation was the likely cause of complaints at 4 wind farms. The complaints from 8 other wind farms may have had "marginal" association with aerodynamic modulation noise.

Four wind farms that generated complaints possibly associated with aerodynamic modulation were evaluated further. These wind farms were commissioned between 1999 and 2002. Wind direction, speed and times of complaints were associated for 2 of the sites and suggested that aerodynamic modulation noise may be a problem between 7% and 25% of the time. Complaints at 2 of the farms have stopped and at one farm steps to mitigate aerodynamic modulation (operational shutdown under certain meteorological conditions) have been instituted.

3. Netherlands Study

F. van den Berg et al. (2008) conducted a postal survey of a group selected from all residents in the Netherlands within 2.5 kilometers (km) of a wind turbine. In all, 725 residents responded (37%). Respondents were exposed to sound between 24 and 54 dB(A). The percentage of respondents annoyed by sound increased from 2% at levels of 30 dB(A) or less, up to 25% at between 40 and 45 dB. Annoyance decreased above 45 dB. Most residents exposed above 45 dB(A) reported economic benefits from the turbines. However, at greater than 45 dB(A) more respondents reported sleep interruption. Respondents tended to report more annoyance when they also noted a negative effect on landscape, and ability to see the turbines was strongly related to the probability of annoyance.

4. Case Reports

A number of un-reviewed reports have catalogued complaints of annoyance and some more severe health impacts associated with wind farms. These reports do not contain measurements of noise levels, and do not represent random samples of people living near wind turbines, so they cannot assess prevalence of complaints. They do generally show that in the people surveyed, complaints are more likely the closer people are to the turbines. The most common complaint is decreased quality of life, followed by sleep loss and headache. Complaints seem to be either from individuals with homes quite close to turbines, or individuals who live in areas subject to aerodynamic modulation and, possibly, enhanced sound propagation which can occur in hilly or mountainous terrain. In some of the cases described, people with noise complaints also mention aesthetic issues, concern for ecological effects, and shadow flicker concerns. Not all complaints are primarily about health.

Harry (2007) describes a meeting with a couple in Cornwall, U.K. who live 400 meters from a wind turbine, and complained of poor sleep, headaches, stress and anxiety. Harry subsequently investigated 42 people in various locations in the U.K. living between 300 meters and 2 kilometers (1000 feet to 1.2 miles) from the nearest wind turbine. The most frequent complaint (39 of 42 people) was that their quality of life was affected. Headaches were reported by 27 people and sleep disturbance by 28 people. Some people complained of palpitations, migraines, tinnitus, anxiety and depression. She also mentions correspondence and complaints from people in New Zealand, Australia, France, Germany, Netherlands and the U.S.

Phipps (2007) discusses a survey of 619 households living up to 10 kilometers (km; 6 miles) from wind farms in mountainous areas of New Zealand. Most respondents lived between 2 and 2.5 km from the turbines (over 350 households). Most respondents (519) said they could see the turbines from their homes, and 80% of these considered the turbines intrusive, and 73% considered them unattractive. Nine percent said they were affected by flicker. Over 50% of households located between 2 and 2.5 km and between 5 and 9.5 km reported being able to hear the turbines. In contrast, fewer people living between 3 and 4.5 km away could hear the turbines. Ninety-two households said that their quality of life was affected by turbine noise. Sixty-eight households reported sleep disturbances: 42 of the households reported occasional sleep disturbances, 21 reported frequent sleep disturbances and 5 reported sleep disturbances most of the time.

The Large Wind Turbine Citizens Committee for the Town of Union (2008) documents complaints from people living near wind turbines in Wisconsin communities and other places in the U.S. and U.K. Contained in this report is an older report prepared by the Wisconsin Public Service Corporation in 2001 in response to complaints in Lincoln County, Wisconsin. The report found essentially no exceedances of the 50 dB(A) requirement in the conditional use permit. The report did measure spectral data accumulated over very short intervals (1 minute) in 1/3 octave bands at several sites while the wind turbines were functioning, and it is of interest that at these sites the sound pressure level at the lower frequencies (below 125 Hz) were at or near 50 dB(A).

Pierpont (2009) postulates wind turbine syndrome, consisting of a constellation of symptoms including headache, tinnitus, ear pressure, vertigo, nausea, visual blurring, tachycardia, irritability, cognitive problems and panic episodes associated with sensations of internal pulsation. She studied 38 people in 10 families living between 1000 feet and slightly under 1 mile from newer wind turbines. She proposes that the mechanism for these effects is disturbance of balance due to "discordant" stimulation of the vestibular system, along with visceral sensations, sensations of vibration in the chest and other locations in the body, and stimulation of the visual system by moving shadows. Pierpont does report that her study subjects maintain that their problems are caused by noise and vibration, and the most common symptoms reported are sleep disturbances and headache. However, 16 of the people she studied report symptoms consistent with (but not necessarily caused by) disturbance of equilibrium.

V. Noise Assessment and Regulation

1. Minnesota noise regulation

The Minnesota Noise Pollution Control Rule is accessible online at: https://www.revisor.leg.state.mn.us/rules/?id=7030 . A summary of the Minnesota Pollution Control Agency (MPCA) noise guidance can be found online at: http://www.pca.state.mn.us/programs/noise.html . The MPCA standards require A-weighting measurements of noise; background noise must be at least 10 dB lower than the noise source being measured. Different standards are specified for day and night, as well as standards that may not be exceeded for more than 10 percent of the time during any hour (L10) and 50 percent of the time during any hour (L50). Household units, including farm houses, are Classification 1 land use. The following are the Class 1 noise limits:

Table 1: Minnesota Class 1 Land Use Noise Limits

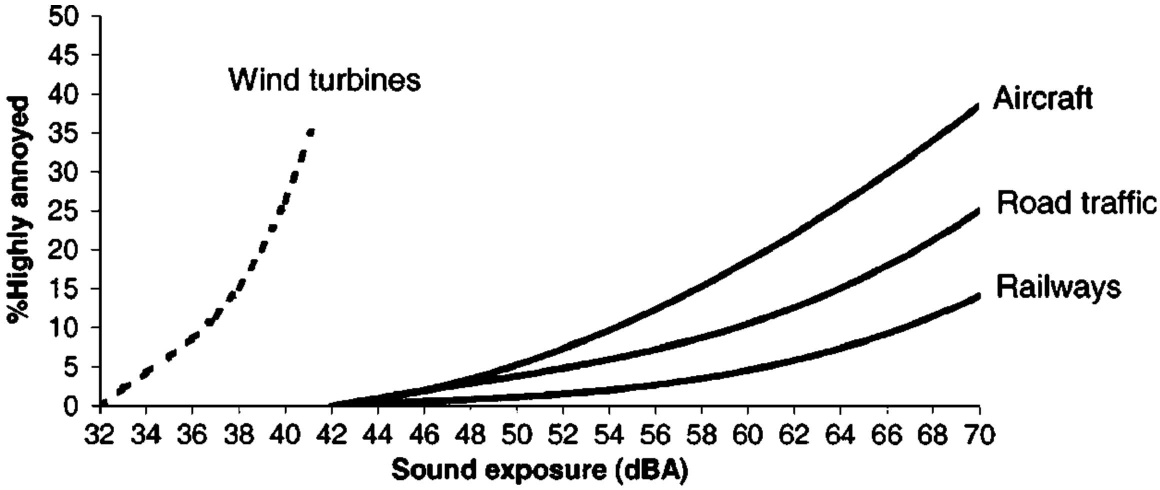
Daytime		Nighttime	
L50	L10	L50	L10
60 dB(A)	65 dB(A)	50 dB(A)	55 dB(A)

These noise limits are single number limits that rely on the measuring instrument to apply an A-weighting filter over the entire presumed audible spectrum of frequencies (20 Hz to 20 KHz) and then integrating that signal. The result is a single number that characterizes the audible spectrum noise intensity.

2. Low frequency noise assessment and regulation

Pedersen and Waye (2004) looked at the relationship between total dB(A) sound pressure and the annoyance of those who are environmentally exposed to noise from different sources. Figure 6 demonstrates the difficulty in using total dB(A) to evaluate annoyance. Note how lower noise levels (dB(A)) from wind turbines engenders annoyance similar to much higher levels of noise exposure from aircraft, road traffic and railroads. Sound impulsiveness, low frequency noise and persistence of the noise, as well as demographic characteristics may explain some of the difference.

Figure 6: Annoyance associated with exposure to different environmental noises



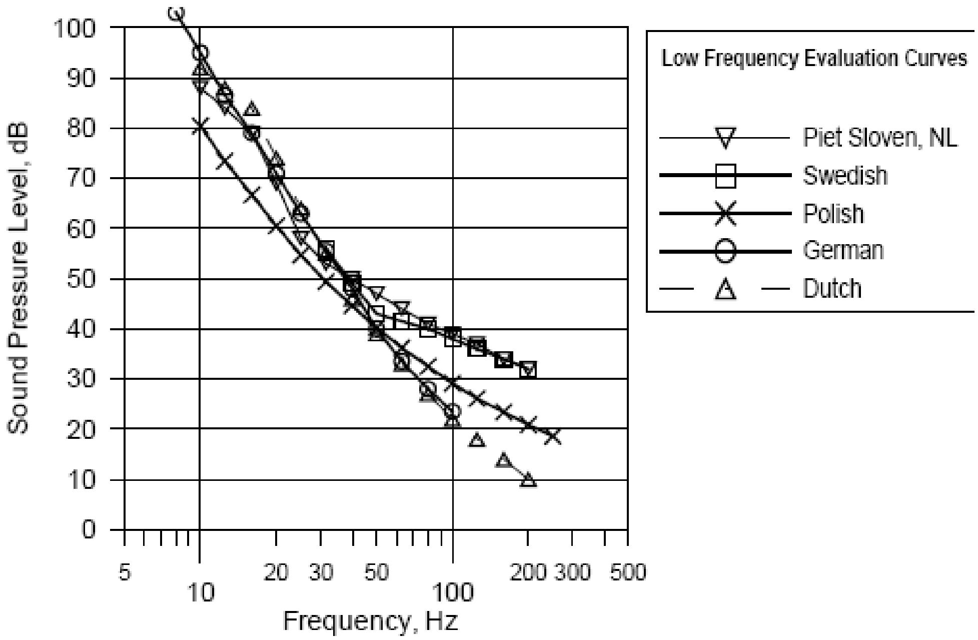
Reprinted with permission from Pedersen, E. and K.P. Waye (2004). Perception and annoyance due to wind turbine noise—a dose–response relationship. The Journal of the Acoustical Society of America 116: 3460. Copyright 2004, Acoustical Society of America.

Kjellberg et al. (1997) looked at the ability of different full spectrum weighting schemes to predict annoyance caused by low frequency audio noise. They found that dB(A) is the worst predictor of annoyance of available scales. However, if 6 dB ("penalty") is added to dB(A) when dB(C) – dB(A) is greater than 15 dB, about 71% of the predictions of annoyance are correct. It is important to remember that integrated, transformed measurements of SPL (e.g. dB(A), dB(C)) do not measure frequencies below 20 Hz. While people detect stimuli below 20 Hz, as discussed in above sections, these frequencies are not measured using an A-weighted or C-weighted meter.

The World Health Organization (WHO) recommends that if dB(C) is greater than 10 dB more than dB(A), the low frequency components of the noise may be important and should be evaluated separately. In addition, WHO says "[i]t should be noted that a large proportion of low-frequency components in noise may increase considerably the adverse effects on health." (WHO, 1999)

Many governments that regulate low frequency noise look at noise within bands of frequencies instead of summing the entire spectrum. A study by Poulsen and Mortensen (Danish Environmental Protection Agency, 2002) included a summary of low frequency noise guidelines. German, Swedish, Polish, and Dutch low frequency evaluation curves were compared (see Figure 7). While there are distinctions in how the evaluation curves are described, generally, these curves are sound pressure criterion levels for 1/3 octaves from about 8 Hz to 250 Hz. Exceedance in any 1/3 octave measurement suggests that the noise may be annoying. However, note that regulations associated with low frequency noise can be quite complex and the regulatory evaluations associated with individual curves can be somewhat different.

Figure 7: 1/3 Octave Sound Pressure Level Low frequency Noise Evaluation Curves



(Danish Environmental Protection Agency, 2002)

The Danish low frequency evaluation requires measuring noise indoors with windows closed; SPL measurements are obtained in 1/3 octave bands and transformed using the A-weighting algorithm for all frequencies between 10 and 160 Hz. These values are then summed into a single metric called $L_{pA,LF}$. A 5 dB "penalty" is added to any noise that is "impulsive". Danish regulations require that 20 dB $L_{pA,LF}$ is not exceeded during the evening and night, and that 25 dB $L_{pA,LF}$ is not exceeded during the day.

Swedish guidance recommends analyzing 1/3 octave bands between 31.5 and 200 Hz inside a home, and comparing the values to a Swedish assessment curve. The Swedish curve is equal to the United Kingdom (UK) Department of Environment, Food and Rural Affairs (DEFRA) low frequency noise criterion curve for overlapping frequencies (31.5 – 160 Hz).

The German "A-level" method sums the A-weighted equivalent levels of 1/3 octave bands that exceed the hearing threshold from 10 – 80 Hz. If the noise is not tonal, the measurements are added. The total cannot exceed 25 dB at night and 35 dB during the day. A frequency-dependent adjustment is applied if the noise is tonal.

In the Poulsen and Mortensen, Danish EPA study (2002), 18 individuals reported annoyance levels when they were exposed through earphones in a controlled environment to a wide range of low frequency environmental noises, all attenuated down to 35 dB, as depicted in Table 2. Noise was simulated as if being heard indoors, filtering out noise at higher frequencies and effectively eliminating all frequencies above 1600 Hz. Noise levels in 1/3 octave SPLs from 8 Hz to 1600 Hz were measured and low frequencies (below 250 Hz) were used to predict annoyance using 7 different methods (Danish, German A-level, German tonal, Swedish, Polish, Sloven, and C-level). Predictions of annoyance were compared with the subjective annoyance evaluations. Correlation coefficients for these analyses ranged from 0.64 to 0.94, with the best correlation in comparison with the Danish low frequency noise evaluation methods.

As would be expected, at 35 dB nominal (full spectrum) loudness, every low frequency noise source tested exceeded all of the regulatory standards noted in the Danish EPA report. Table 2 shows the Danish and Swedish regulatory exceedances of the different 35 dB nominal (full spectrum) noise.

Table 2: 35 dB(A) (nominal, 8 Hz-20KHz) Indoor Noise from Various Outdoor Environmental Sources

	Traffic Noise	Drop Forge	Gas Turbine	Fast Ferry	Steel Factory	Generator	Cooling Compressor	Discotheque
Noise	67.6 dB(lin)	71.1 dB(lin)	78.4 dB(lin)	64.5 dB(lin)	72.7 dB(lin)	60.2 dB(lin)	60.3 dB(lin)	67.0 dB(lin)
Noise ≥ 20 Hz	35.2 dB(A)	36.6 dB(A)	35.0 dB(A)	35.1 dB(A)	33.6 dB(A)	36.2 dB(A)	36.6 dB(A)	33.6 dB(A)
	62.9 dB(C)	67.3 dB(C)	73.7 dB(C)	61.7 dB(C)	66.0 dB(C)	58.6 dB(C)	59.0 dB(C)	57.8 dB(C)
Danish Environmental Protection Agency	14.5 dB	21.5 dB *	14.8 dB	15.0 dB	13.1 dB	16.1 dB	14.0 dB	18.0 dB *
Swedish National Board of Health and Welfare	14.1 dB	19.7 dB	15.9 dB	16.8 dB	15.5 dB	18.3 dB	16.0 dB	10.0 dB

* includes 5 dB "penalty"

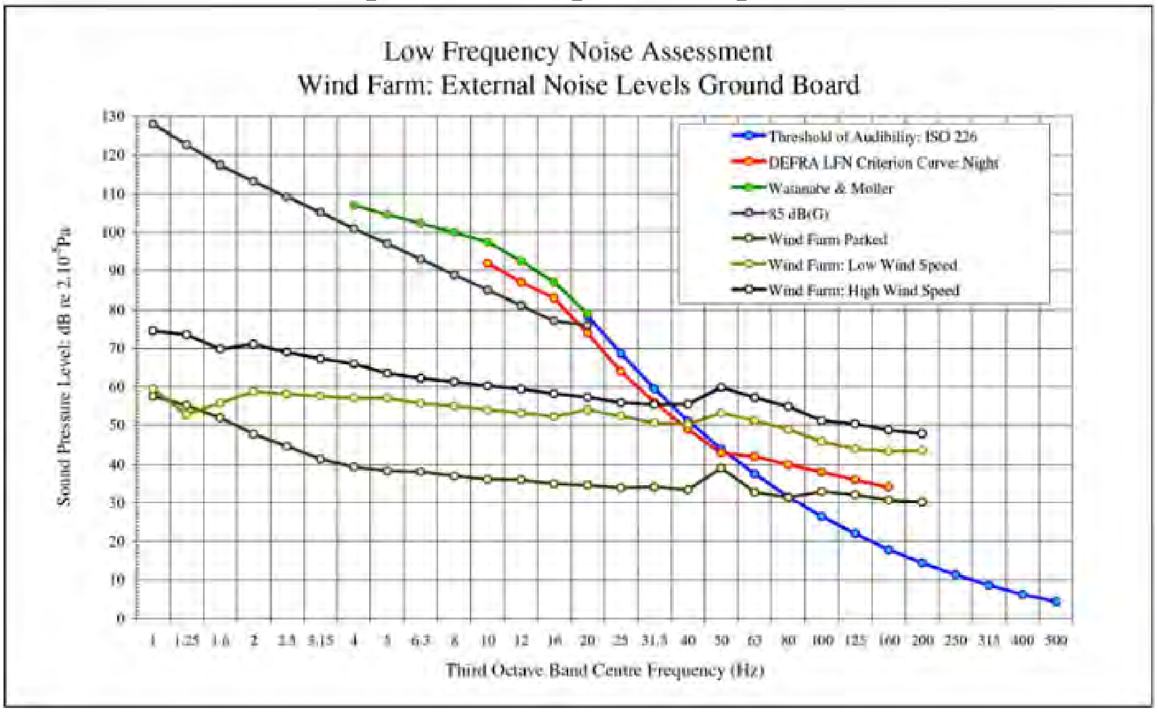
Noise adjusted to dB(lin), dB(A), dB(C) scales. Calculated exceedances of Danish and Swedish indoor criteria. (data from Danish Environmental Protection Agency, 2002)

In their noise guidance, the WHO (1999) recommends 30 dB(A) as a limit for “a good night’s sleep”. However, they also suggest that guidance for noise with predominating low frequencies be less than 30 dB(A).

3. Wind turbine sound measurements

Figure 8 shows examples of the SPLs at different frequencies from a representative wind turbine in the United Kingdom. Sound pressure level measurements are reported for a Nordex N-80 turbine at 200 meters (UK Department of Transport and Industry, 2006) when parked, at low wind speeds, and at high wind speeds. Figure 8 also includes, for reference, 3 sound threshold curves (ISO 226, Watanabe & Moller, 85 dB(G)) and the DEFRA Low Frequency Noise Criterion Curve (nighttime).

Figure 8: Low Frequency Noise from Wind Farm: Parked, Low Wind Speed, and High Wind Speed

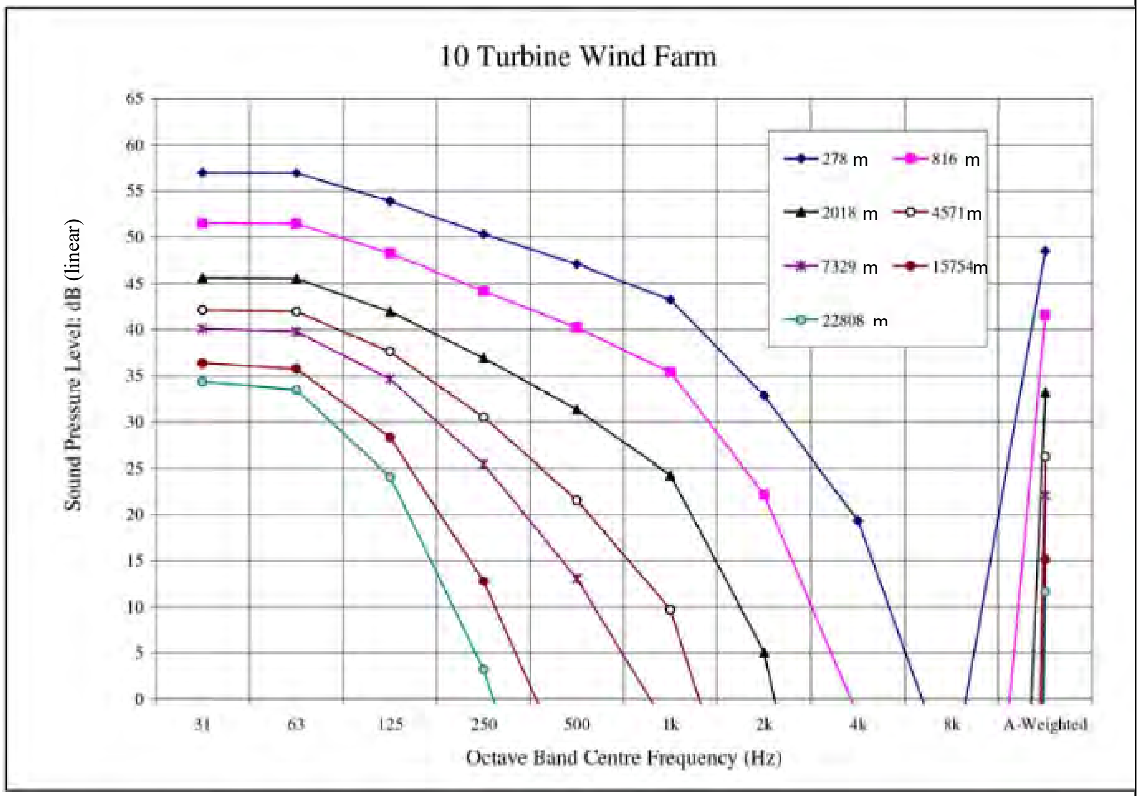


(UK Department of Transport and Industry, 2006)

In general, sound tends to propagate as if by spherical dispersion. This creates amplitude decay at a rate of about -6 dB per doubling of distance. However, low frequency noise from a wind turbine has been shown to follow more of a cylindrical decay at long distances, about -3 dB per doubling of distance in the downwind direction (Shepherd and Hubbard, 1991). This is thought to be the result of the lack of attenuation of low frequency sound waves by air and the atmospheric refraction of the low frequency sound waves over medium to long distances (Hawkins, 1987).

Figure 9 shows the calculated change in spectrum for a wind farm from 278 meters to 22,808 meters distant. As one moves away from the noise source, loudness at higher frequencies decreases more rapidly (and extinguishes faster) than at lower frequencies. Measurement of A-weighted decibels, shown at the right of the figure, obscures this finding.

Figure 9: Change in Noise Spectrum as Distance from Wind Farm Changes



(UK Department of Transport and Industry, 2006)

Thus, although noise from an upwind blade wind turbine is generally broad spectrum, without a tonal quality, high frequencies are efficiently attenuated by both the atmosphere, and by walls and windows of structures, as noted above. As a result, as one moves away from a wind turbine, the low frequency component of the noise becomes more pronounced.

Kamperman and James (2008) modeled indoor noise from outdoor wind turbine noise measurements, assuming a typical vinyl siding covered 2X4 wood frame construction. The wind turbine noise inside was calculated to be 5 dB less than the noise outside. Model data suggested that the sound of a single 2.5 MW wind turbine at 1000 feet will likely be heard in a house with the windows sealed. They note that models used for siting turbines often incorporate structure attenuation of 15dB. In addition, Kamperman and James demonstrate that sound from 10 2.5 MW turbines (acoustically) centered 2 km (1¼ mile) away and with the nearest turbine 1 mile away will only be 6.3 dB below the sound of a single turbine at 1000 feet (0.19 mile).

4. Wind turbine regulatory noise limits

Ramakrishnan (2007) has reported different noise criteria developed for wind farm planning. These criteria include common practices (if available) within each jurisdiction for estimating background SPLs, turbine SPLs, minimum setbacks and methods used to assess impacts. Reported US wind turbine noise criteria range from: ambient + 10 dB(A) where ambient is assumed to be 26 dB(A) (Oregon); to 55 dB(A) or "background" + 5 dB(A) (Michigan). European criteria range from 35 dB(A) to 45 dB(A), at the property. US setbacks range from 1.1 times the full height of the turbine (consenting) and 5 times the hub height (non-consenting; Pennsylvania); to 350 m (consenting) and 1000 m (non-consenting; Oregon). European minimum setbacks are not noted.

VI. Conclusions

Wind turbines generate a broad spectrum of low-intensity noise. At typical setback distances higher frequencies are attenuated. In addition, walls and windows of homes attenuate high frequencies, but their effect on low frequencies is limited. Low frequency noise is primarily a problem that may affect some people in their homes, especially at night. It is not generally a problem for businesses, public buildings, or for people outdoors.

The most common complaint in various studies of wind turbine effects on people is annoyance or an impact on quality of life. Sleeplessness and headache are the most common health complaints and are highly correlated (but not perfectly correlated) with annoyance complaints. Complaints are more likely when turbines are visible or when shadow flicker occurs. Most available evidence suggests that reported health effects are related to audible low frequency noise. Complaints appear to rise with increasing outside noise levels above 35 dB(A). It has been hypothesized that direct activation of the vestibular and autonomic nervous system may be responsible for less common complaints, but evidence is scant.

The Minnesota nighttime standard of 50 dB(A) not to be exceeded more than 50% of the time in a given hour, appears to underweight penetration of low frequency noise into dwellings. Different schemes for evaluating low frequency noise, and/or lower noise standards, have been developed in a number of countries.

For some projects, wind velocity for a wind turbine project is measured at 10 m and then modeled to the height of the rotor. These models may under-predict wind speed that will be encountered when the turbine is erected. Higher wind speed will result in noise exceeding model predictions.

Low frequency noise from a wind turbine is generally not easily perceived beyond ½ mile. However, if a turbine is subject to aerodynamic modulation because of shear caused by terrain (mountains, trees, buildings) or different wind conditions through the rotor plane, turbine noise may be heard at greater distances.

Unlike low frequency noise, shadow flicker can affect individuals outdoors as well as indoors, and may be noticeable inside any building. Flicker can be eliminated by placement of wind turbines outside of the path of the sun as viewed from areas of concern, or by appropriate setbacks.

Prediction of complaint likelihood during project planning depends on: 1) good noise modeling including characterization of potential sources of aerodynamic modulation noise and characterization of nighttime wind conditions and noise; 2) shadow flicker modeling; 3) visibility of the wind turbines; and 4) interests of nearby residents and community.

VII. Recommendations

To assure informed decisions:

- Wind turbine noise estimates should include cumulative impacts (40-50 dB(A) isopleths) of all wind turbines.
- Isopleths for dB(C) - dB(A) greater than 10 dB should also be determined to evaluate the low frequency noise component.
- Potential impacts from shadow flicker and turbine visibility should be evaluated.

Any noise criteria beyond current state standards used for placement of wind turbines should reflect priorities and attitudes of the community.

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EXHIBIT
26

Property Value Impacts of Wind Turbines and the Influence of Attitudes toward Wind Energy

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ABSTRACT *The lack of consensus in the literature on wind turbines and property values suggests that factors such as attitudes toward wind energy may influence whether turbines will impact property values. Based on identified attitudes at the municipality level in the Canadian province of Ontario, this study compares impacts on property values, estimated using a difference-in-differences hedonic approach, between municipalities that oppose wind energy development and those that have not expressed opposition. The results indicate that wind turbines have negatively impacted property values in "unwilling host" municipalities, while no significant impacts are found in unopposed municipalities.* (JEL R11, R52)

1. Introduction

The literature on property value impacts of wind turbines has grown substantially in recent years in response to the rapid expansion of wind energy development and the ensuing concerns expressed by local residents regarding potential impacts on property values, an issue that has become quite prominent and contentious in a number of jurisdictions. However, a general consensus on this issue has not been reached; while some studies have found evidence that wind turbines have negatively impacted surrounding property values (Heintzelman and Tuttle 2012; Jensen, Panduro, and Lundhede 2014; Gibbons 2015; Dröes and Koster 2016; Sunak and Madlener 2016), other studies have not found significant impacts on property values (Sims, Dent, and Oskrochi 2008; Hoen et al. 2011; Lang, Opaluch, and Sfinarolakis 2014; Vyn and McCullough 2014; Hoen et al. 2015).

The lack of consensus in the literature may have initially been attributable in part to the prevalence of studies in which impacts were estimated based on relatively few observations in close proximity to wind turbines. This issue may have inhibited the ability to detect significant impacts, particularly since impacts on property values are likely to be relatively small (Hoen et al. 2015). In fact, this issue was pervasive among early studies that did not find significant impacts. More recent studies have avoided this issue through the use of larger data sets, and have subsequently been more likely to find evidence of negative impacts (Gibbons 2015; Dröes and Koster 2016; Sunak and Madlener 2016). However, even among studies that avoid the small numbers issue, a lack of consensus still exists, as other recent studies with large numbers of observations in close proximity to turbines have not found significant impacts (Lang, Opaluch, and Sfinarolakis 2014; Hoen et al. 2015). This suggests that the lack of consensus is not solely due to data shortcomings; rather, there may be another explanation for the differences in results among these studies. For example, there may be contextual factors specific to each jurisdiction that influence whether wind turbines will impact property values, such as the level of involvement that residents have in the approval process for a wind energy facility, the number of turbines constructed, and the amount of compensation provided to the community by the developer. Indeed, Heintzelman, Vyn, and Guth (2017) speculated that such factors may have contributed to differences in impacts on property values observed in their study between two bordering jurisdictions from a single wind farm constructed in one of the jurisdictions.

The variation in the results across previous studies could also be attributed to heteroge-

Land Economics • November 2018 • 94 (4): 496–516
ISSN 0023-7639; E-ISSN 1543-8325

Appendix materials are freely available at http://le.uwpress.org and via the links in the electronic version of this article.

neous attitudes toward wind energy (which could arise due to differences in contextual factors). A related body of literature has demonstrated evidence of differences across jurisdictions in wind energy attitudes and in perceptions of impacts, which may contribute to differences in observed impacts on property values. If residential property buyers support wind energy and do not perceive wind turbines to impact property values, they would not adjust their bids to reflect a disamenity impact. Conversely, buyers who perceive turbines to have a negative impact on property values would reduce their bids for affected properties, or would not bid at all. Accordingly, if a community has a relatively high proportion of buyers who perceive turbines to be a disamenity, the resulting lower demand for properties in closer proximity to turbines would cause a reduction in prices for these properties, while a community with a low proportion of buyers who perceive turbines to be a disamenity is unlikely to experience a similar decline in demand for these properties. Hence, this heterogeneity in perceptions may result in different levels of demand across jurisdictions for properties in close proximity to turbines, which may be contributing to the lack of consensus in the literature regarding property value impacts.

The possibility that variation in impacts could be due to differences in perceptions for wind energy has not been examined empirically. The primary impediment to examining this issue is difficulty in measuring and identifying differences in attitudes or perceptions across property buyers or across jurisdictions. In general, studies on attitudes toward wind energy are conducted through surveys of individuals, typically within a single jurisdiction, from which it can be difficult to extrapolate results to identify differences across jurisdictions.

However, the Canadian province of Ontario provides a setting that permits the identification of differences in attitudes toward wind energy at the municipality level. Some municipalities in Ontario have encouraged wind energy development, while other municipalities have fought to prevent the siting of wind farms within their communities. The ability to observe these municipal-level responses to wind energy development enables the evaluation and comparison of property value impacts between jurisdictions with different attitudes: that is, those that are opposed to wind energy development in their communities versus those that are not opposed.

This paper uses a difference-in-differences hedonic approach to estimate the impacts of wind turbines on rural residential property values in Ontario, and takes advantage of the identified attitudes toward wind energy to compare the estimated impacts between municipalities opposed to and municipalities unopposed to wind energy development. The results of this paper indicate differences in the estimated impacts of turbines on property values between the two sets of municipalities, where negative impacts are found in municipalities that have expressed opposition to wind energy development, while no significant impacts are found in unopposed municipalities. Hence, this paper addresses a gap in the literature by providing evidence that may explain the variation in results across previous related studies.

Literature on Wind Energy Attitudes and Perceptions

It is evident from the literature that heterogeneous attitudes toward and perceptions of wind energy exist. For example, Baxter, Morzaria, and Hirsch (2013) compared perceptions of wind energy between two Ontario communities—one with turbines and one without—and found significantly more support for wind energy in the community that already had turbines. This study also found that residents of the community with turbines were less concerned about impacts on health and property values. Direct relationships between proximity to turbines and support for wind energy have also been observed in other studies (Krohn and Dambourg 1999; Warren et al. 2005). However, evidence regarding the nature of these relationships is not consistent across all jurisdictions. For example, Swofford and Slattery (2010) found that support levels for wind energy in Texas were lower for residents in close proximity to turbines than for residents farther away, while other studies found no difference in support due to proximity (Johansson and Laike 2007; Graham, Stephenson, and Smith 2009). Hence, these results suggest that attitudes toward wind energy vary across jurisdictions, and are not necessarily linked to proximity of existing turbines.[1]

Attitudes toward wind energy can be linked to perceptions regarding potential impacts of turbines. Bidwell (2013) noted that attitudes toward wind energy may be developed in response to real or anticipated effects of wind farms. He also pointed out that while wind energy development can have both positive and negative impacts, undesirable effects have played a larger role in shaping public perception. In particular, attitudes toward wind energy are influenced to a large extent by perceived impacts related to the aesthetics of wind turbines (Warren et al. 2005). Another factor related to the influence of aesthetics is cumulative effects, where attitudes may also be influenced by the number of turbines in the viewshed. For example, Ladenburg and Dahlgaard (2012) and Ladenburg, Termansen, and Hasler (2013) found negative relationships between the number of turbines viewed daily and attitudes toward wind energy development. However, in a subsequent study, Ladenburg (2015) found that the number of turbines viewed daily had little to no impact on attitudes.

There are a number of other factors identified in the literature that can influence perceptions of wind energy and its associated impacts. Perceptions may be influenced by the opinions of people within one's social network (Devine-Wright 2005), which implies that perceptions may vary across communities depending on the opinions and attitudes of a community's most vocal or influential members. Similarly, perceptions may be influenced by the local media (Deignan, Harvey, and Hoffman-Goetz 2013). Perceptions of wind turbines may also be influenced by the level of involvement that local residents have in the development of a wind project (Heintzelman, Vyn, and Guth 2017).[2]

Differences across jurisdictions in perceptions of wind turbines and their potential impacts, which could be underlying the variation in the results of previous studies on property value impacts, have been observed in the literature. For example, Walker et al. (2014) found evidence that perceptions of the impacts of wind turbines on property values varied between residents of neighboring communities in Ontario, and suggested that social dynamics may have contributed to the differences in perceptions. It is noteworthy that the community in which residents were less likely to perceive negative impacts was located in close proximity to one of the first wind farms constructed in the province, while the community in which residents were more likely to perceive negative impacts was in close proximity to a more recently developed wind farm. This coincides with the findings of Warren et al. (2005), where perceptions of wind turbines were more negative among residents in close proximity to a proposed wind farm than among residents in close proximity to an existing wind farm. Van der Horst (2007) noted that this is consistent with the literature on risk perception, as anything new and unfamiliar can increase people's dislike due to the higher level of perceived risk.

Negative perceptions regarding the impacts of wind turbines can contribute to opposition to wind energy development. Johansson and Laike (2007) found that people with negative attitudes toward wind energy, in particular due to the perceived visual effects, were more likely to have a strong intention to oppose turbines. A number of other factors can contribute to community opposition to wind energy projects, such as a perceived lack of fairness in the planning process (Gross 2007), lack of communication and consultation with

[1] It should be noted that these differences in attitudes could occur due to differences in the stage of wind energy development (i.e., proposed vs. existing). Similarly, there could be differences between general attitudes toward wind energy and attitudes toward a specific project. While these distinctions are important to make for understanding factors that influence attitudes and that contribute to differences in these attitudes, the key result from the perspective of the current study is that differences in attitudes have been found to exist across jurisdictions.

[2] There may also be other factors that influence perceptions of wind energy, such as demographic or socioeconomic factors. Developing a better understanding of the primary factors that influence these perceptions would be a useful topic for future study.

residents (Krohn and Damborg 1999; Wolsink 2007), distrust of the developer, particularly for outside developers with no ties to the community (Jobert, Laborgne, and Mimler 2007), and the persuasiveness of local opposition groups (Van der Horst 2007).

Vocal opposition that focuses on the negative effects can in turn further contribute to shaping perceptions. Chapman, Joshi, and Fry (2014) examined this phenomenon in Australia, where they found that negative information presented by an anti–wind energy organization regarding health issues caused by wind farms impacted the expectations and perceptions of local residents. This suggests that the degree of negative attention wind energy receives could influence the perception of those who were previously indifferent to wind energy or who were not previously concerned about the potential impacts of wind turbines, which could result in greater homogeneity of attitudes (i.e., opposition to wind energy) for residents within a jurisdiction. This may have occurred to some degree in Ontario.

Background of the Study Area

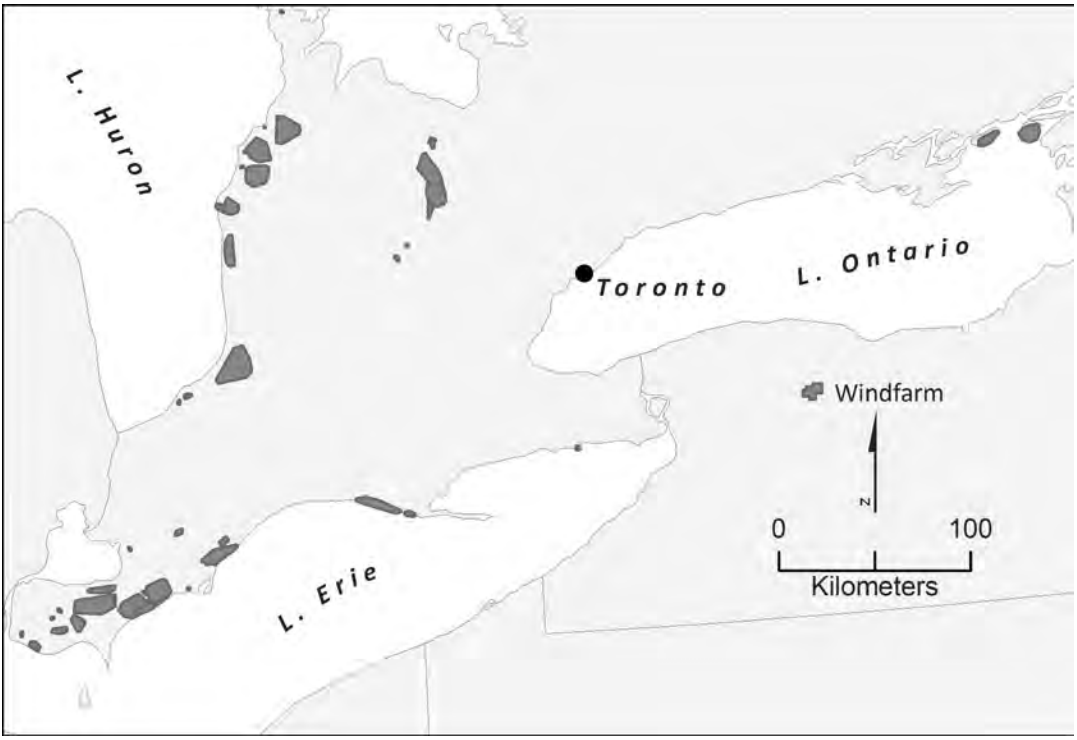
The development of wind energy in the province of Ontario represents an interesting case study. When the first industrial wind farms were constructed in the mid-2000s, there was relatively little opposition to them and few concerns expressed publicly. These wind farms were sited in municipalities that chose to host them. A study on the first major industrial wind farm in the province found no significant impacts on property values (Vyn and McCullough 2014). The Green Energy Act, 2009, paved the way for the rapid expansion of the wind energy industry in the province. In an attempt to aggressively increase the proportion of energy derived from renewable sources, the provincial government offered significant financial incentives, primarily through energy rates much higher than the existing market rate, to encourage wind energy development.

The number of commercial wind turbines in the province increased from 10 in 2003 to over 2,300 in 2015, with the majority of this increase occurring after the implementation of the Green Energy Act. Figure 1 provides a map of the locations of wind farms in the province, which are primarily concentrated in rural areas along the Great Lakes. The rapid expansion of wind energy development captured the public's attention, and many of the factors discussed above that influence wind energy attitudes and perceptions emerged during this period of expansion. While some public meetings were held to discuss proposed wind projects, local residents essentially had little to no influence regarding the approval and siting of these projects. Residents of many of the communities with recently constructed or proposed wind projects felt that the approval and siting processes were unfair, as the provincial government approved these projects despite feedback from residents, and even from municipalities, indicating their opposition to the projects and their concerns regarding impacts of wind turbines.

The perceived unwillingness of the provincial government to listen to or address these concerns led to a groundswell of more vocal opposition and the formation of grassroots organizations, such as Wind Concerns Ontario, that actively opposed wind energy development on behalf of residents in communities across the province. Concerns from these opposition groups regarding impacts of wind turbines, such as impacts on health and property values, have been expressed prominently in local news media. This media attention, which has increased substantially in recent years, may have influenced attitudes toward wind energy and perceptions of turbine impacts.

Another source of controversy was the provincial government's ability to override municipal decisions regarding wind energy development. To protest the lack of local control over the siting of wind farms, a large number of municipalities passed resolutions to declare their jurisdiction to be an "unwilling host" for wind energy (see Figure 2). While this designation could not prevent wind farms from being sited in their jurisdiction, it was a means to express their opposition to local wind energy development and to the province's regulations regarding the siting of wind farms. While attitudes are unlikely to be uniform across all residents of unwilling host municipalities, it is assumed that the prevailing sentiment among

Figure 1
Map of Wind Farms in Southern Ontario
Source: http://ontario-wind-turbines.org/.

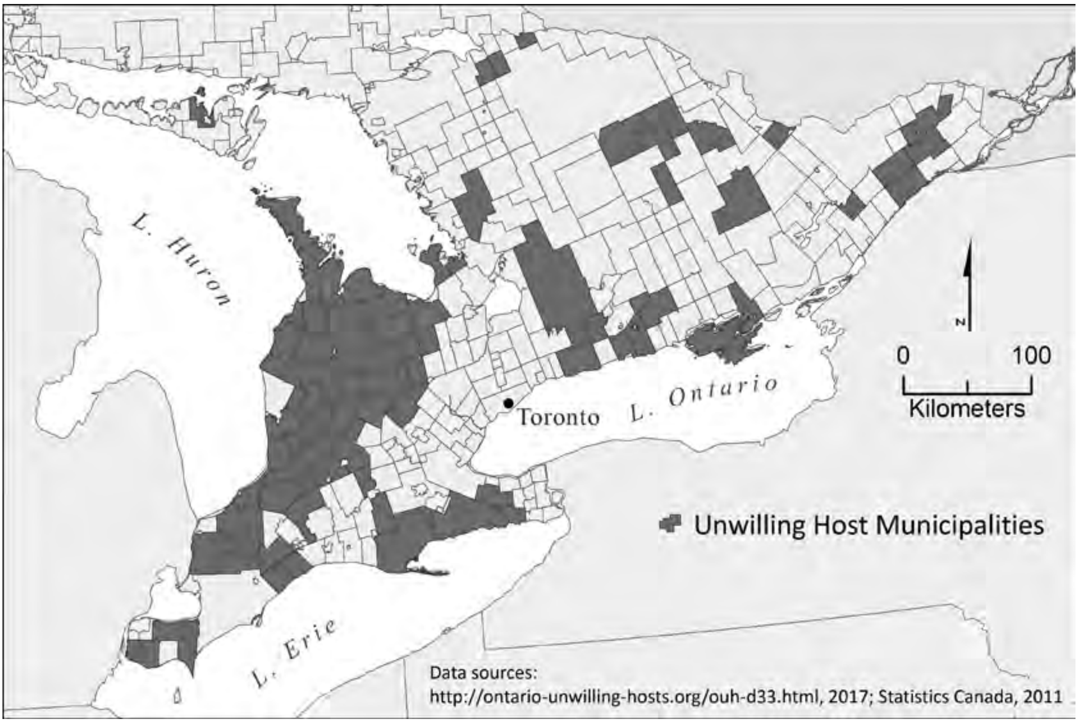


residents of these municipalities would be opposition to wind energy.

Other municipalities, however, did not oppose wind energy development, and some actually encouraged it within their jurisdiction. For example, the municipality of Chatham-Kent encouraged the siting of wind projects within its borders, in part for economic reasons as the local economy had been suffering due to the substantial loss of manufacturing jobs. This coincides with a finding by Jobert, Laborgne, and Mimler (2007), where declining economic conditions made residents view a wind project proposal more favorably. This promotion of wind energy development within municipalities such as Chatham-Kent may indicate a difference in attitudes toward and perceptions of wind energy relative to unwilling host municipalities. The more favorable perceptions of wind energy may influence the nature of property value impacts observed in these communities. This paper examines the extent to which this has occurred in the province of Ontario.

The analysis conducted in this paper consists of three components. The first component involves estimating the average impacts of wind turbines on property values across southwestern Ontario, where wind energy development in the province has been concentrated. While an earlier study examined the impacts of the first industrial wind farm in the province and found no evidence of negative impacts (Vyn and McCullough 2014), an updated and more comprehensive study is needed to determine whether the rapid expansion of wind energy development in the province and the subsequent increase in concerns expressed publicly and through the media have contributed to a greater impact on property values. In the second component of the analysis, impacts are estimated and compared

Figure 2
Map of Unwilling Host Municipalities in Southern Ontario



between the two groups of municipalities, based on the identified attitudes of municipalities toward wind energy development.

Finally, the third component of the analysis examines the impact of turbine density on property values. Previous studies have estimated density impacts for other disamenities such as oil and gas wells (Boxall, Chan, and McMillan 2005), shale gas wells (Gopalakrishnan and Klaiber 2014; Muehlenbachs, Spiller, and Timmins 2015), and livestock operations (Palmquist, Roka, and Vukina 1997; Herriges, Secchi, and Babcock 2005). In the literature on wind turbines and property values, which tends to focus on the impacts of turbine proximity or turbine visibility, the impact of turbine density has received relatively little examination, the results of which are varied. Gibbons (2015) found that the impact on property values increased with turbine density; conversely, Dröes and Koster (2016) found no evidence that additional turbines increased the impact on property values. Similarly, varied results are also found in stated preference studies regarding marginal willingness to pay for fewer turbines. For example, Meyerhoff, Ohl, and Hartje (2010) found that some segments of survey respondents were willing to pay for smaller wind farms, while other segments preferred wind farms with more turbines. The analysis conducted in the current study estimates the marginal effects of additional turbines within specific distance ranges and compares marginal effects between the two groups of municipalities.

2. Data

The data used to empirically evaluate the impact of wind turbines on property values in Ontario consists of rural residential property sales across southwestern Ontario between January 2002 and July 2013, as recorded by the Municipal Property Assessment Corporation (MPAC),[3] the organization responsible for the assessment of all properties in the province. Observations that are not characterized as open-market sales are omitted from the data, as well as observations with missing information. In an effort to reduce the geographic extent of the study area and enhance the similarity of observations between the treatment and control groups, sales of properties greater than 20 km from the nearest wind turbine are excluded from the data. In addition, in order to avoid the influence of outliers, observations with the top 1% and bottom 1% of sale prices are omitted from the data.[4] After these omissions, the data set used for the analysis consists of 22,159 sales. This data set includes a considerable number of variables that describe each property. A number of spatial variables, calculated using ArcGIS, are added to the data set, including the distance from each property to the nearest wind turbine as well as distances to urban areas.

Variables Accounting for Turbine Impacts

Appropriate specification of variables that account for the potential impact of wind turbines on property values is a relatively complicated endeavor, given the large number of wind farms in Ontario, many of which are in close proximity to each other and were constructed at different points in time. Thirty-seven wind farms were constructed in southwestern Ontario during the study period, the majority of which were completed between 2008 and 2012. These wind farms range considerably in size from 3 to 110 turbines. As evident in Figure 1, many wind farms are in close proximity to other wind farms. This complicates the specification of variables that account for turbine impacts, as in many cases the abutting wind farms were constructed at different points in time. Hence, this variable specification must account for the time period for each wind farm during which an impact is expected to occur.

[3] See https://www.mpac.ca.

[4] This did not affect the nature of the results with respect to the estimated turbine impacts, but it did improve the model fit.

While impacts on property values are assumed to be most likely to occur after the turbines have been constructed, an impact may also occur following the announcement of a wind farm, at which time the approximate location of the turbines may be known though the impact on the landscape (i.e., the disamenity) is not yet observable. In Ontario, the intense controversy surrounding wind energy development led to considerable media attention and public awareness of this issue, and public opposition to proposed projects began very early in the process. As a result, buyers of residential properties in areas with proposed wind farms would most likely have been aware of the impending potential disamenity.

Since the study data include sales that occurred both before and after the wind farms were announced and subsequently constructed, three time periods are specified for each wind farm: preannouncement (PA), announcement (AN), and postconstruction (PC). The preannouncement period occurs prior to the announcement of the wind farm, the announcement period covers the time period from the announcement of the wind farm to the construction of the turbines, and the postconstruction period is the time period following completion of turbine construction.

In addition to the temporal considerations, the variables accounting for turbine impacts must also take into account the relative proximity of properties to turbines. Based on the nature of the visual and aural disamenities associated with turbines, the impact is expected to be greatest in closest proximity to turbines and to diminish with distance from the turbines. To account for the variation in the expected impact that occurs with distance from turbines, previous studies have used either a continuous distance specification, such as inverse distance (e.g., Heintzelman and Tuttle 2012), or a discrete distance specification, such as through the use of distance bands (e.g., Hoen et al. 2015). While a continuous specification imposes structure on the data and may affect the accuracy of the estimated impact in close proximity to turbines, this approach is preferable in situations with limited sales data. Conversely, a discrete specification avoids the issues inherent in the continuous specification and permits the estimation of impacts within specific distance ranges. However, without adequate numbers of observations for each distance range, models based on this specification are unlikely to find statistically significant impacts unless the magnitude of the impact is quite large.

Since the data used for this analysis include a large number of sales in close proximity to turbines, the turbine impacts are captured through a set of distance bands, specified in 1 km increments up to 5 km, based on the distance to the nearest turbine. The numbers of sales in each distance band are provided in Table 1 for each time period. It is evident from this table that each band includes considerable numbers of sales, which supports the appropriateness of conducting the analysis using a discrete distance approach. By comparison, the study by Hoen et al. (2015) included 376 observations within 1 mi of turbines in the postconstruction period, while the current study includes 300 sales within 1 km (0.62 mi) in the postconstruction period.

The 5 km outer limit for expected impacts is based on a visual assessment of wind farms in Ontario, which indicated that visibility of turbines beyond this distance was negligible at best. This distance limit follows that of Vyn and McCullough (2014) and is similar to the 3 mi extent of anticipated impacts established by Hoen et al. (2015). To ensure that this distance limit is appropriate, additional specifications were tested to account for impacts beyond 5 km, but significant impacts were not found to occur beyond 5 km. As a result, all properties between 5 km and 20 km from the turbines are included in the control group and are not divided up into additional distance bands.

The distance band variables are then interacted with each of the time period variables to create the variables that account for the impact of turbines, where an interaction term is equal to 1 for a property for which the nearest turbine is within the corresponding distance band and time period, and 0 otherwise. Since impacts are anticipated to occur within 5 km of turbines and in both the announcement and postconstruction periods, the interaction terms for these time periods and distance bands are expected to capture the impacts of turbines.

However, as mentioned above, the specification of these variables is complicated

Table 1

Numbers of Sales within Specific Distance Ranges, by Time Period

	Full Sample			Opposed Municipalities			Unopposed Municipalities		
Distance	Preannouncement	Announcement	Postconstruction	Preannouncement	Announcement	Postconstruction	Preannouncement	Announcement	Postconstruction
0–1 km	118	149	300	67	111	262	51	38	38
1–2 km	422	269	347	354	217	310	68	52	37
2–3 km	298	254	324	275	219	292	23	35	32
3–4 km	213	196	364	189	167	328	24	29	36
4–5 km	389	252	724	367	221	659	22	31	65
5–20 km	7,110	4,550	5,880	6,739	4,113	4,793	371	437	1,087

by situations in which a property is in close proximity to multiple wind farms that were constructed at different times. For example, the sale of a property could occur during the announcement period for one wind farm in close proximity and during the postconstruction period for another. Of the 4,619 sales of properties within 5 km of at least one wind farm, 916 are within 5 km of two wind farms, 136 are within 5 km of three wind farms, 266 are within 5 km of four wind farms, and 94 are within 5 km of five wind farms. This implies that for some properties there could be multiple interaction terms categorized as 1, which raises the question as to how to appropriately account for turbine impacts for these properties; in other words, would the impact be equally attributable to all nearby turbines or just to the one that is most prominent?

Based on the assumption stated above that the potential impact associated with turbines declines with distance, this implies that the impact should be attributed primarily to the turbine from the closest wind farm rather than equally among all nearby wind farms.[5] As such, for the subset of properties within 5 km of multiple wind farms in the announcement and postconstruction periods, only one turbine interaction term is categorized as 1, with all other interaction terms set equal to 0.

To determine the interaction term that captures the most prominent impact, and is thus categorized as 1, a ranking system is imposed based on two assumptions: (1) an impact is more likely to occur, or to be greater in magnitude, for the turbine in closest proximity; and (2) within each distance band an impact is more likely to occur, or to be greater in magnitude, in the postconstruction period than in the announcement period, due to the observability of the impact on the landscape. Hence, the ranking system is organized as follows: *PC* × *0–1 km*, *AN* × *0–1 km*, *PC* × *1–2 km*, *AN* × *1–2 km*, . . . , *PC* × *4–5 km*, *AN* × *4–5 km*, where a 1 is assigned to the highest-ranked interaction term for each property in close proximity to multiple wind farms.

The implications of this ranking system can be best explained through an example. For a property that is 1 to 2 km from one wind farm in the announcement period, 2 to 3 km from a second wind farm in the postconstruction period, and 4 to 5 km from a third wind farm in the postconstruction period, there would be three interaction terms that would initially be categorized as 1. In this case, based on the relative rankings, only *AN* × *1–2 km* would be categorized as 1, while both *PC* × *2–3 km* and *PC* × *4–5 km* would be categorized as 0 rather than as 1.

However, the assumptions inherent in the imposed ranking system for specifying the interaction term that is set equal to 1 for properties close to multiple wind farms may influence the results. To address the potential bias that may arise for this subset of properties due to these assumptions, the robustness of the results under two alternate specifications of the interaction terms is examined.

The first alternate specification accounts for the argument that impacts may be attributable to a greater extent to an existing disamenity source rather than a future disamenity source, even if the future disamenity is in closer proximity. Accordingly, this specification imposes a ranking system comprising the postconstruction interaction terms for the distance bands up to 5 km (i.e., *PC* × *0–1 km*, *PC* × *1–2 km*, . . . , *PC* × *4–5 km*), followed by the announcement interaction terms up to 5 km. Under this specification, for the example given above for a property in close proximity to three wind farms, the expected impact of the wind farm that is 2 to 3 km away in the postconstruction period would be more prominent than that of the unconstructed turbine 1 to 2 km away for the wind farm in the announcement period. As a result, in this case only *PC* × *2–3 km* would be categorized as 1, while *AN* × *1–2 km* and *PC* × *4–5 km* would be categorized as 0.

The second alternate specification relaxes the assumption that an impact is attributable primarily to only one (i.e., the closest) wind farm and the corollary requirement that only one interaction term is equal to 1, and allows for impacts associated with the nearest wind farm in each of the announcement and postconstruction periods, whereby interac-

[5] Any impact of turbines from other nearby wind farms would be more likely captured through the impact of turbine density, which is addressed later in this paper.

tion terms for both periods can be equal to 1. This allows for accounting separately for announcement impacts and postconstruction impacts, which may differ. Under this specification, for the example given above, both *PC × 2–3 km* and *AN × 1–2 km* would be categorized as 1.

Turbine Impacts in Opposed and Unopposed Municipalities

To account for differences in impacts between municipalities that have declared their jurisdictions to be "unwilling hosts" for wind energy development and those that have not, the variables accounting for the turbine impacts are interacted with categorical variables representing the two groups of properties: those located in unwilling host municipalities, referred to in this paper as "opposed municipalities," and those located in municipalities that have not passed resolutions expressing their opposition to the siting of wind turbines within their jurisdiction, referred to as "unopposed municipalities."[6] This breakdown is based on the list of unwilling hosts compiled by Wind Concerns Ontario.[7] As evident in Figure 2, a large proportion of municipalities in the study area of southwestern Ontario (the area west of Toronto and bounded by the Great Lakes) are unwilling hosts; of the 59 municipalities included in the data, 44 are unwilling hosts. As a result, the opposed subsample (comprising 19,683 sales) is much larger than that of the unopposed subsample (2,476 sales). Accordingly, there are considerably fewer sales in close proximity to turbines in the unopposed subsample. For example, of the 300 sales in the 0 to 1 km distance band in the postconstruction period, 38 are located in unopposed municipalities. The number of sales within each distance band is broken down between the two subsamples in Table 1.

[6]This designation does not imply that all residents of these municipalities are unopposed to wind turbines, but rather that the municipality has not passed resolutions declaring their opposition. This suggests that there is not a critical mass of residents opposed to wind turbines within any of these municipalities.

[7]See http://www.windconcernsontario.ca.

Impacts of Turbine Density

Property values may be impacted not only by proximity to the nearest turbine but also by the number of turbines in close proximity. In fact, the disamenity impact of wind turbines may increase as the density of turbines in close proximity increases. To account for the variation in impact with the number of nearby turbines, variables are specified that represent turbine density (number of turbines) within specific distances, namely, 1 km, 2 km, and 5 km. Since the potential disamenity associated with turbine density would be most prominent in the postconstruction period (when the visual impact of multiple turbines on the landscape can actually be observed), these density variables are interacted with the postconstruction time period variable. Specifying densities within different distance ranges allows for examining how the impact of turbine density varies with proximity to these turbines. It is anticipated that the impact of a specific density would be greater for smaller distance ranges, since the turbines would be in closer proximity. The number of turbines within each of the distance limits for properties sold in the postconstruction period ranges from 0 to 7 within 1 km, from 0 to 24 within 2 km, and from 0 to 113 within 5 km. Hence, given the magnitude of turbine density in close proximity to many of the properties in the data set, it is important to assess the impact of turbine density on property values. This involves estimating marginal effects of additional turbines for each of the three distance ranges. The impacts of turbine density are then estimated separately for opposed municipalities and for unopposed municipalities, using interaction terms between the density variables and categorical variables representing each of the two groups of municipalities. The estimation of the impacts associated with turbine density provides a valuable complement to the analysis based on the impacts associated with proximity to the nearest turbine.

Control Variables

Control variables are included in the model to account for the value associated with specific attributes of the property, particularly those related to the house. Attributes accounting for the value associated with the house include square footage, basement area, age of the house, quality level (on a scale of 1 to 10, as rated by MPAC), the numbers of stories, bathrooms, bedrooms, and fireplaces, and the existence of a pool and of air conditioning. Other attributes of the property include the lot size, existence of a garage, and the area of other structures on the property, such as garden sheds. The relative value of specific property types is also accounted for by including variables to represent mobile homes, seasonal properties, and waterfront properties, which are broken down into two categories: lakefront properties and other waterfront properties. Location variables are included to account for urban influence and for the impacts of surrounding property types. Urban influence is accounted for by the distance to the Greater Toronto Area, to the nearest city, and to the nearest major highway interchange. Variables are also included to account for abutting commercial and industrial properties. Summary statistics for the control variables are provided in Table 2 for the full data set, and are also broken down by type of municipality (i.e., opposed and unopposed).

Spatial and temporal fixed effects variables are also included in the model. The temporal fixed effects include sets of year and month categorical variables to account for annual and seasonal variation in property values. Spatial fixed effects, specified at the township level, are included to account for unobserved local factors that can influence property values, which can bias the results of hedonic models. The use of spatial fixed effects can substantially reduce omitted variable bias (Kuminoff, Parmeter, and Pope 2010). An alternative approach to addressing this issue is through the use of spatial econometric methods, which account for the spatial dependence that contributes to omitted variable bias. As a robustness check, a spatial lag model is estimated to examine whether potential omitted variable bias may be influencing the results.

3. Methods

Following a number of previous related studies (Vyn and McCullough 2014; Hoen et al. 2015; Heintzelman, Vyn, and Guth 2017), a hedonic analysis is used to estimate the impact of wind turbines on property values, based on a difference-in-differences approach. The empirical model is represented by the following equation:

$$\ln(P_{ijt}) = \alpha_i + \sum_k \delta(T_i \cdot D_i) + \sum_l \beta \ln(X_i) \cdot C_i + \tau_t + \rho_j + \mu_{jt} + \varepsilon_{ijt}, \quad [1]$$

where P_{ijt} is the sale price for property i in township j and in time t; T_i is a vector of categorical variables that indicate the time period for the nearest wind farm at the time of sale (i.e., preannouncement, announcement, and postconstruction); D_i is a vector of distance band categorical variables (i.e., 0–1 km, 1–2 km, 2–3 km, 3–4 km, 4–5 km, and 5–20 km) that indicate the location of the property with respect to the distance from the nearest turbine; X_i is a vector of control variables, as discussed in the previous section and summarized in Table 2[8]; τ_t and ρ_j represent the temporal and spatial fixed effects, respectively; and μ_{jt} and ε_{ijt} represent the local and individual error terms, respectively.

Since the study area encompasses multiple wind farms, the hedonic model represented by equation [1] is used to estimate an average impact on surrounding property values across these wind farms. Pooling all transactions across this area rather than estimating impacts separately for each wind farm allows for basing this estimated impact on a large number of transactions, which may enhance the ability to detect significant impacts, particularly since the impacts of wind turbines tend to be relatively small in magnitude. Conversely, estimating separate impacts for each wind farm may be less likely to generate significant impacts or an accurate estimate of these impacts, as there are relatively few sales in close proximity to many of the individual wind farms.

While combining observations across multiple wind farms may preclude the ability to account for varying impacts across wind farms, this may be less of an issue given the

[8] Categorical variables and continuous variables with relatively low integer values are not logged.

Table 2

Summary Statistics for the Dependent and Control Variables for the Full Data Set (n = 22,159) and for Opposed Municipalities (n = 19,683) and Unopposed Municipalities (n = 2,476)

		Full Sample				Opposed		Unopposed	
Variable	Description	Mean	Std. Dev.	Min.	Max.	Mean	Std. Dev.	Mean	Std. Dev.
Price	Sale price of property (Canadian dollars)	230,725	100,057	50,000	650,000	226,139	96,288	267,184	120,013
Lot size	Size of property (acres)	1.640	6.893	0.030	224.570	1.604	7.094	1.929	5.013
Age	Age of house (years)	35.986	30.826	0.000	188.000	35.702	31.196	38.239	27.613
Living area	Living area of house (sq. ft.)	1,481.598	517.749	326.000	8,511.000	1,456.370	496.162	1,682.146	630.023
Basement area	Area of basement (sq. ft.)	878.343	558.281	0.000	3,750.000	863.311	538.183	997.840	686.267
Stories	Number of stories	1.405	0.461	1.000	3.000	1.412	0.463	1.346	0.433
Bedrooms	Number of bedrooms	3.045	0.737	1.000	20.000	3.032	0.728	3.144	0.799
Bathrooms	Number of bathrooms	1.608	0.647	0.500	13.500	1.595	0.635	1.714	0.727
Fireplaces	Number of fireplaces	0.395	0.566	0.000	4.000	0.378	0.555	0.527	0.632
Pool	=1 if property has a pool	0.043	0.203	0.000	1.000	0.038	0.191	0.084	0.277
Air conditioning	=1 if house has air conditioning	0.338	0.473	0.000	1.000	0.312	0.463	0.543	0.498
Quality	House quality index (1–10)	5.992	0.539	1.000	9.500	5.976	0.528	6.119	0.604
Garage	=1 if property has a garage	0.733	0.442	0.000	1.000	0.726	0.446	0.795	0.404
Other structures	Area of secondary structures (sq. ft.)	189.011	684.447	0.000	14,691.000	166.048	646.524	371.560	912.422
Industrial	=1 if abutting industrial property	0.006	0.078	0.000	1.000	0.005	0.071	0.014	0.118
Commercial	=1 if abutting commercial property	0.021	0.142	0.000	1.000	0.019	0.135	0.037	0.189
Mobile home	=1 if residence is a mobile home	0.001	0.031	0.000	1.000	0.001	0.032	0.000	0.020
Seasonal	=1 if seasonal property	0.052	0.222	0.000	1.000	0.057	0.232	0.010	0.098
Waterfront: lake	=1 if lakefront property	0.020	0.141	0.000	1.000	0.023	0.149	0.000	0.000
Waterfront: other	=1 if other waterfront property	0.016	0.124	0.000	1.000	0.017	0.128	0.008	0.087
GTA	Distance to the Greater Toronto Area (km)	103.592	79.374	18.381	318.043	95.710	70.926	166.253	109.444
City	Distance to the nearest city (km)	18.048	21.730	0.000	110.415	19.101	22.714	9.681	6.757
Highway	Distance to the nearest highway (km)	48.168	34.704	0.097	205.001	50.887	35.563	26.551	14.099
Density 1 km	Number of turbines within 1 km	0.030	0.298	0.000	7.000	0.030	0.296	0.032	0.315
Density 2 km	Number of turbines within 2 km	0.153	1.150	0.000	24.000	0.153	1.149	0.152	1.157
Density 5 km	Number of turbines within 5 km	1.142	5.029	0.000	113.000	1.155	5.074	1.042	4.657

geographic proximity of the wind farms (i.e., all are within southwestern Ontario). In addition, due in part to the short period of time during which most of the wind farms in Ontario were constructed, the turbine sizes are relatively uniform across the province. This contrasts the settings for other recent studies such as those by Gibbons (2015) and Dröes and Koster (2016), where turbine height and capacity vary considerably. As a result of this homogeneity, the impact on property values in southwestern Ontario is unlikely to vary across wind farms due to differences in turbine characteristics.

However, there may be variation across the study area in the values associated with each of the property and location control variables, which may influence the estimated turbine impacts. To account for this variation, the property and location variables (X_i) are interacted with county categorical variables (C_i). Further, in an effort to ensure that the treatment and control groups comprise properties within similar market areas, sales of properties greater than 20 km from the nearest turbine are excluded from the analysis.

The analysis for this study comprises three components. In the first component, equation [1] is used to estimate the average impacts of turbines at various distances on property values across southwestern Ontario. For the second component of the analysis, the variables accounting for the impacts of turbines ($T_i{\cdot}D_i$) are interacted with each of the two groups of properties: those located in opposed (i.e., unwilling host) municipalities (M_1) and those located in unopposed municipalities (M_2). The model in equation [1] is then estimated with the two sets of time period–distance band interaction terms ($T_i{\cdot}D_i{\cdot}M_i$). Postestimation tests are conducted to determine whether the differences in the estimated impacts between the two groups of municipalities are statistically significant. Finally, given the large numbers of turbines that exist in certain areas of the province, the third component estimates the impact of turbine density on property values, as an alternative to the impact of proximity to the nearest turbine. This involves replacing the interaction terms ($T_i{\cdot}D_i$) in equation [1] with a variable that accounts for the (logged) number of wind turbines in close proximity. For comparison purposes, the impacts of turbine density and the marginal effects of additional turbines are estimated based on the numbers of turbines within 1 km, 2 km, and 5 km. The turbine density variables are then interacted with each of the two groups of municipalities to examine for differences in the impacts of turbine density between opposed and unopposed municipalities.

The difference-in-differences specification is conducted following the approach used by Hoen et al. (2015), which is based on the model results for the set of interaction terms of time period and distance band variables (i.e., $T_i{\cdot}D_i$). The interaction term for the preannouncement period and the 5 to 20 km distance band is omitted from the model and represents the control group, as impacts are not expected to occur within this distance range or during this time period. For each of the other distance bands, the impacts in the announcement and postconstruction periods are estimated based on the change in property values that occurred within the band since the preannouncement period relative to the change in property values that occurred over the same period in the 5 to 20 km band. For example, the impact in the 0 to 1 km band in the postconstruction period is calculated as the difference between the change in property values that occurred between the preannouncement and postconstruction periods in the 0 to 1 km band and the change in property values over the same period in the 5 to 20 km band. From the model results, this would be calculated by taking the coefficient for *PC × 0–1 km* and subtracting the coefficients for *PA × 0–1 km* and *PC × 5–20 km*. Similarly, the impact in the 0 to 1 km band in the announcement period is calculated from the model results by subtracting the coefficients for *PA × 0–1 km* and *AN × 5–20 km* from the coefficient for *AN × 0–1 km*.

4. Results

Turbine Impacts

The model results for the interaction terms accounting for the impacts of turbines on property values are provided in Table 3. Based on these coefficients, the difference-in-differences approach described in the previous section is used to estimate impacts on property values in the announcement and postconstruction periods within each of the distance bands up to 5 km from turbines. It is evident from the final column of Table 3 that negative impacts are found up to 4 km from the nearest wind turbine in both the announcement and postconstruction periods. These impacts range from 4.14% to 7.91% in the announcement period and from 5.33% to 8.35% in the postconstruction period. Hence, these impacts do not vary substantially in magnitude across this area, and a decline in magnitude with distance from turbines is not observed, which suggests that impacts may be similar across the area within which turbines are (or will be) potentially visible. These impacts, particularly at greater distances from the turbines, may also be exacerbated by expectations or perceptions of potential impacts that may be attributable to the widespread controversy and public attention in the province regarding this issue.

The results in Table 3 also indicate that the estimated coefficient for the 0 to 1 km distance band in the preannouncement period is negative and statistically significant, which is unexpected. This suggests that in some cases wind farms may have been constructed in areas with relatively lower house prices.[9] However, despite the lower house prices in the preannouncement period, the results of the difference-in-differences approach indicate that prices are further reduced in the subsequent announcement and postconstruction periods.

Table 3

Estimated Coefficients for the Interaction Terms (Time period × Distance band) and Resulting Turbine Impacts on Property Values

Variable	Coef.	Std. Err.	Impact (%)
PA × 0–1 km	–0.060**	0.021	
PA × 1–2 km	–0.008	0.013	
PA × 2–3 km	0.024	0.014	
PA × 3–4 km	0.026	0.015	
PA × 4–5 km	0.026*	0.012	
AN × 0–1 km	–0.132**	0.019	–7.25**
AN × 1–2 km	–0.047**	0.015	–4.14*
AN × 2–3 km	–0.055**	0.015	–7.91**
AN × 3–4 km	–0.047**	0.016	–7.36**
AN × 4–5 km	0.010	0.015	–1.85
AN × 5–20 km	0.003	0.006	
PC × 0–1 km	–0.130**	0.016	–5.33*
PC × 1–2 km	–0.101**	0.015	–7.49**
PC × 2–3 km	–0.063**	0.015	–6.90**
PC × 3–4 km	–0.076**	0.014	–8.35**
PC × 4–5 km	0.026*	0.012	1.49
PC × 5–20 km	–0.015*	0.008	
Number of observations	22,159		
Adjusted R-squared	0.780		

*, ** Statistical significance at the 5% and 1% levels, respectively.

Control Variables

The results of the control variables are provided in Appendix Table A1. Since the control variables are interacted with county categorical variables, rather than including an exhaustive list of the results for each of the 14 counties, this table provides a summary of these results. First, for each variable it indicates the percentage of counties for which coefficients have the expected sign and are statistically significant at the 10% level or lower. Descriptive statistics are then provided for these coefficients, which indicate the magnitude of the mean as well as the range of coefficient values. Variables for which coefficients have the expected sign and are statistically significant in at least 75% of the counties include lot size, age, living area, basement area, number of bathrooms, house quality, and lakefront property. Coefficients for several other variables have the expected sign and are statistically significant in at least 60% of counties.

The results for many of the control variables are consistent across counties in the direction of impact on property values. Exceptions include numbers of bedrooms and fireplaces, mobile home, and the distance variables. While bedrooms were expected to positively impact values, the lack of consistency in the direction, as well as the lack of significance, of the coefficients for bedrooms could be due to the fact that with living area held constant an additional bedroom may result in smaller rooms. As a result, the impact of an additional

[9] To determine whether factors such as demographic characteristics contributed to this effect, an additional model was tested that included average household income and population density. However, these factors were not found to influence house prices, and their inclusion in the model did not change the results.

bedroom on the value of a house is ambiguous. The exception that occurs for the impact of a mobile home is an unexpected positive impact in one county (Lambton); however, the coefficient estimate in this county is based on only one observation. Similarly, the impact of fireplaces is found to be positive in all counties except for one (Simcoe).[10] The directions of effects for the remaining variables are generally consistent with expectations.

Robustness Checks

The robustness of these results is examined under two alternate specifications of the interaction terms that account for the turbine impacts, in order to address the potential bias due to the assumptions that are imposed in the original specification of these terms. The results of the interaction terms for both alternate specifications are provided in Appendix Table A2, along with the estimated percentage impacts on property values. In the interest of space, the results of the control variables, which are very similar to those of the original specification, are not provided in this table.[11] For the first alternate specification, significant negative impacts are found in the announcement period in the 0 to 1 km band and between 2 and 4 km from the nearest turbine, and in the postconstruction period between 0 and 4 km. Similar results are found under the second alternate specification, with an additional significant impact found in the 4 to 5 km band in the announcement period. The magnitudes of the impacts for the alternate specifications are similar to those observed in the primary model.

Another robustness check involves the use of a spatial model to account for spatial autocorrelation, which may affect the accuracy and validity of the hedonic model results. To determine whether spatial dependence exists, a Moran's *I* test is conducted. The results of this test ($I = 0.105$; $p < 0.001$) indicate that the null hypothesis of no spatial autocorrelation is rejected. This issue can be addressed through the use of either a spatial lag model or a spatial error model, depending on the nature of the correlation (Kim, Phipps, and Anselin 2003). With a higher log-likelihood value for the spatial lag model (3,749.162) than the spatial error model (3,117.296), the spatial lag model is used to account for spatial autocorrelation.[12] The spatial weight matrix for this model is specified based on the 10 nearest neighbors.[13] The number of observations in the spatial lag model (18,045) is lower than in the ordinary least squares model, as multiple sales of the same properties are omitted to avoid including observations with the same coordinates in the specification of the spatial weight matrix. In cases of multiple sales, only the most recent sale remains in the data, following the approach used by Hoen et al. (2015).

The results of the spatial lag model, provided in Appendix Table A2, indicate that the nature of the estimated impacts is similar to that of the primary model, where significant negative impacts are found within 4 km of turbines in both the announcement and postconstruction periods. This implies that spatial autocorrelation has not significantly influenced the results with respect to the turbine impacts. Similarly, Hoen et al. (2015) found that although spatial dependence existed it did not bias the results for the variables of interest, as the estimated coefficients in the spatial models were quite similar to those of the ordinary least squares models.

Hence, the results of the primary model appear to be robust to alternate specifications of the interaction terms that account for the turbine impacts as well as to the use of a spatial model to account for potential bias associated with spatial dependence. This robustness enhances confidence in the results. The similarity in results between the original specification of the interaction terms and the alternate specifications could be due in part to the relatively low number of properties that are within 5 km of multiple wind farms, particu-

[10] It should be noted that there are only 121 observations in Simcoe County (0.5% of all observations).

[11] However, these results are available from the author upon request. This is also the case for all subsequent models estimated in this paper, for which only the results of the interaction terms are provided.

[12] However, the results are similar for both the spatial lag and spatial error models.

[13] An alternate spatial weight matrix, based on an inverse distance specification, is also tested. The results are consistent across both specifications.

Table 4

Results of the Interaction Terms Accounting for Turbine Impacts on Property Values for Properties in Opposed Municipalities and for Properties in Unopposed Municipalities, with Wald Tests for Differences in Impacts

	Opposed Municipalities			Unopposed Municipalities			Difference	
Variable	Coefficient	Std. Err.	Impact	Coefficient	Std. Err.	Impact	*F*-Statistic	Prob. > *F*
PA × 0–1 km	–0.042	0.026		–0.098**	0.037			
PA × 1–2 km	0.005	0.014		–0.076*	0.034			
PA × 2–3 km	0.030*	0.015		–0.049	0.047			
PA × 3–4 km	0.033*	0.016		–0.019	0.045			
PA × 4–5 km	0.031*	0.013		–0.004	0.047			
AN × 0–1 km	–0.136**	0.022	–9.10%**	–0.142**	0.041	–4.40%	0.76	0.3820
AN × 1–2 km	–0.051**	0.017	–5.61%**	–0.038	0.036	3.75%	4.36	0.0368
AN × 2–3 km	–0.063**	0.017	–9.09%**	–0.011	0.040	3.70%	4.64	0.0313
AN × 3–4 km	–0.056**	0.018	–8.63%**	0.001	0.043	1.81%	2.88	0.0897
AN × 4–5 km	0.013	0.016	–1.94%	–0.001	0.042	0.16%	0.11	0.7361
AN × 5–20 km	0.002	0.006		0.001	0.016			
PC × 0–1 km	–0.144**	0.017	–8.55%**	–0.074	0.039	7.33%	8.13	0.0043
PC × 1–2 km	–0.107**	0.016	–9.42%**	–0.085*	0.040	3.78%	7.62	0.0058
PC × 2–3 km	–0.065**	0.016	–7.93%**	–0.067	0.042	2.85%	3.20	0.0735
PC × 3–4 km	–0.077**	0.015	–9.31%**	–0.071	0.039	–0.63%	2.31	0.1284
PC × 4–5 km	0.033**	0.013	1.52%	–0.050	0.031	0.02%	0.07	0.7871
PC × 5–20 km	–0.013	0.008		–0.046**	0.016			

Note: n = 22,159; adjusted R^2 = 0.781.
*, ** Statistical significance at the 5% and 1% levels, respectively.

larly where sales occur in different time periods. Of the 4,619 sales of properties within 5 km of at least one wind farm, only 346 sales occurred during both the postconstruction and announcement periods for wind farms within 5 km. As such, the interaction terms for the majority of observations in close proximity to turbines are not affected by the imposed ranking system.

Opposed Municipalities versus Unopposed Municipalities

To examine for differences in impacts associated with differences in attitudes toward wind energy, as identified at the municipality level through declarations as unwilling hosts, the original model is updated by interacting the set of turbine impact variables with categorical variables representing properties in opposed municipalities and properties in unopposed municipalities. Following the estimation of this model, Wald tests are conducted to examine for statistically significant differences in the estimated impacts within each distance band and time period interaction. It is evident from the results of the interaction terms and the Wald tests, provided in Table 4, that differences exist in the estimated turbine impacts between the two types of municipalities. Significant negative impacts of turbines on property values are found in opposed municipalities between 0 and 4 km from the turbines in both the announcement and postconstruction periods, while no significant impacts are found in unopposed municipalities. The magnitudes of the impacts in opposed municipalities are greater than those in the original model, ranging from 5.61% to 9.10% in the announcement period and from 7.93% to 9.42% in the postconstruction period.

The results of the Wald tests indicate that a number of statistically significant differences are found in the estimated impacts between the two groups of municipalities. Specifically, significant differences in impacts are found in the announcement period for the 1 to 2 km, 2 to 3 km, and 3 to 4 km (at the 10% level) distance bands and in the postconstruction period for the 0 to 1 km, 1 to 2 km, and 2 to 3 km (at the 10% level) distance bands. Hence, in most cases in which significant impacts are found in opposed municipalities, these impacts are significantly greater than those in unopposed municipalities.

Overall, the results of this component of the analysis provide evidence to support the hypothesis that the nature of impacts of wind

Table 5
Results of the Turbine Density Variables for Specific Distance Ranges and Marginal Effects of Additional Turbines

	Full Sample			Opposed Municipalities			Unopposed Municipalities		
Variable	1 km	2 km	5 km	1 km	2 km	5 km	1 km	2 km	5 km
Turbine density	–0.057**	–0.044**	–0.028**	–0.065**	–0.049**	–0.030**	–0.004	–0.016	–0.016*
	(0.012)	(0.006)	(0.003)	(0.013)	(0.006)	(0.003)	(0.031)	(0.015)	(0.007)
Marginal Effects (dollars)									
1st turbine	–8,141	–6,382	–4,069	–9,342	–7,037	–4,333	–639	–2,385	–2,342
2nd turbine	–4,616	–3,645	–2,345	–5,272	–4,007	–2,495	–371	–1,383	–1,357
5th turbine	–1,982	–1,580	–1,031	–2,249	–1,732	–1,096	–165	–614	–604
10th turbine	–1,000	–803	–527	–1,127	–877	–560	–87	–318	–312
20th turbine	–491	–398	–265	–551	–435	–282	–46	–160	–156
50th turbine	–189	–156	–106	–212	–169	–111	–19	–65	–63

Note: Standard errors in parentheses.
*, ** Statistical significance at the 5% and 1% levels, respectively.

turbines on property values is influenced by attitudes toward wind energy, as turbines are found to impact property values in municipalities that indicated opposition to wind energy development but no significant impacts are found in municipalities that have not indicated opposition. Further, the differences between the two groups of municipalities in these estimated impacts are statistically significant in a number of cases.

However, it should be noted that there are relatively few sales within each distance band in the subsample of sales in unopposed municipalities (see Table 1), which may reduce the ability to detect significant impacts. As evident in Table 4, the standard errors for the interaction terms in the unopposed model are about twice the size of those in the opposed model. Despite this potential limitation, the fact that several of the estimated impacts in opposed municipalities are found to be significantly greater than those in unopposed municipalities supports the implication of the model results that impacts are greater in opposed municipalities than in unopposed municipalities.

Turbine Density Impacts

The final component of the analysis examines the impacts of turbine density on property values and estimates marginal effects[14] of additional turbines within specific distance ranges. The results of this analysis, provided in Table 5, indicate that turbine density within all three distance ranges (1 km, 2 km, and 5 km) significantly impacts property values, such that higher densities contribute to greater negative impacts. This is consistent with expectations, as multiple turbines within a property's viewshed would increase the visual disamenity. As evident in Table 5, the marginal effect is greatest for the first turbine and declines considerably for each additional turbine within the specified distance range, which is also consistent with expectations. For example, the marginal effect of the first turbine within 5 km is $4,069, while the marginal effect of the fifth turbine is $1,031 and the marginal effect of the fiftieth turbine is only $106. The marginal effects are also greater in magnitude for smaller distance ranges, as the marginal effect of the first turbine within 1 km is $8,141, or 3.5% of the average sale price of $230,725, which is approximately double the marginal effect of the first turbine within 5 km, while the marginal effect of the first turbine within 2 km is $6,382.

Cumulative impacts on property values can also be determined for a specific number of turbines within each distance range. For example, a turbine density of 10 within 1 km would reduce property value by $26,851, or 11.6% of the average value, a density of 10 within 2 km would reduce property value by $21,271, or 9.2%, and a density of 10 within 5

[14] Marginal effects are estimated using the "margins" postestimation command in Stata.

km would reduce property value by $13,746, or 6.0%.

Turbine density impacts are also estimated separately for opposed municipalities and unopposed municipalities to determine whether these impacts differ between the two groups of municipalities. Similar to the results of the analysis based on distance to the nearest turbine, turbine density is found to significantly impact property values in opposed municipalities (see Table 5), while in unopposed municipalities significant impacts are found only for the 5 km density. Once again, the magnitudes of the impacts, as well as the marginal effects, are greater in opposed municipalities than across all sales. The marginal effect of the first turbine in opposed municipalities is $9,342, or 4.1%, for the 1 km distance range, $7,037, or 3.1%, for the 2 km range, and $4,333, or 1.9%, for the 5 km range. The results of postestimation tests indicate that the impacts in opposed municipalities for all three densities are significantly greater (at the 10% level or better) than those in unopposed municipalities. Hence, these results support those of the analysis based on distance to the nearest turbine, which enhances confidence in these results. These results also provide further evidence of differences in turbine impacts across jurisdictions with different attitudes toward wind energy.

5. Conclusions

The results of this study provide strong evidence that wind turbines in Ontario have negatively impacted surrounding property values. The results also demonstrate that these impacts increase with the number of turbines in close proximity. Hence, this study adds to the evidence contributed by more recent empirical studies that wind facilities can impact property values. This study then takes the analysis a step further by examining for differences in impacts among jurisdictions with different attitudes toward wind energy. The observed differences in estimated impacts on property values between "unwilling host" municipalities and unopposed municipalities suggest that the nature of turbine impacts within a jurisdiction (i.e., negative impacts or lack of impacts) may be influenced by attitudes toward wind energy in that jurisdiction, and that public perception regarding wind energy and its potential impacts is a prominent contributing factor to the nature of observed impacts on property values. This is the first study to demonstrate such differences and to provide empirical evidence that may help to explain the lack of consensus in the literature regarding impacts of wind turbines on property values.

With a large number of sales in close proximity to turbines, this study overcomes one of the primary concerns associated with earlier studies on this issue. However, this issue may yet arise in the component of the analysis that breaks down impacts between opposed and unopposed municipalities, as the numbers of sales within specific distance bands for unopposed municipalities are somewhat low, ranging from 29 to 65 for distance bands within 5 km of turbines in the announcement and postconstruction periods. This may represent a potential limitation of this analysis, as the lack of significant impacts observed for properties in these municipalities may be attributable in part to this issue. However, these results are supported by those of the turbine density analysis for unopposed municipalities, which is not affected by the low numbers issue since the postconstruction observations are not divided into distance bands.

The assumptions imposed in the specification of variables accounting for turbine impacts also has the potential to influence the results, which may be a caveat of this study. But once again, the general result of this specification (i.e., turbines negatively impact values) is supported by the results of the turbine density analysis, for which such potentially limiting assumptions are not imposed. In addition, the results under alternate specifications of these variables are quite similar. It should also be noted that these variables are specified based on distance to the nearest turbine as a proxy for the visual disamenity; however, views of turbines may be affected by landscape features such as trees and buildings. While other recent studies have used digital elevation tools to estimate turbine visibility (e.g., Gibbons 2015), which can enhance the disamenity measure based on distance, there are limitations associated with the available elevation data for the study area that inhibit the ability to accurately measure the visibility of turbines from individual properties. As a result, turbine impacts are estimated based solely on a distance measure. The existence of better quality view data for the study area could potentially allow for improving the precision of these estimated impacts.

Another caveat of this study is that the declaration by municipalities to be unwilling hosts is assumed to be representative of attitudes toward wind energy (i.e., opposition to wind energy) for residents of the municipality. However, it is unlikely that all residents within unwilling host municipalities are opposed to wind energy, or that all buyers of residential properties adjust their bids to account for the perceived disamenity associated with turbines. Nonetheless, it is most likely reflective of the predominant sentiment among residents of the municipality, given that these declarations were made in response to public input and feedback from residents regarding this issue. Conversely, such declarations may not have been made by unopposed municipalities due to a lack of public opposition to wind energy within these municipalities and the subsequent lack of pressure from residents to have their municipalities declared to be unwilling hosts.

The finding of significant negative impacts of wind turbines on property values in Ontario is consistent with the results of recent studies such as those by Gibbons (2015) and Dröes and Koster (2016), but differs from the results of Hoen et al. (2015) and Lang, Opaluch, and Sfinarolakis (2014), which did not find significant impacts. The significant negative impacts found in this study extend approximately 4 km from turbines in both the announcement and postconstruction periods. This range of impacts is similar to that of Dröes and Koster (2016), where negative impacts on property values were found to extend 2 to 3 km from the turbines. The magnitude of the impact on property values in Ontario is found to range from 4.14% to 8.35% within 4 km of turbines. These impacts are similar in magnitude to those estimated by Gibbons (2015), who found an impact of 5% to 6% on properties within 2 km of wind farms. Contrary to the results of Gibbons (2015), the magnitude of impacts estimated in this study is not found to decline with distance from the turbines over the 4 km extent of significant impacts, although a decline does occur beyond 4 km.

The results of this study contrast those of a previous study on property value impacts in Ontario by Vyn and McCullough (2014), the results of which indicated no significant impacts of turbines. However, this difference in results is not entirely surprising, due to differences in the settings and time periods between these two studies. First, the study by Vyn and McCullough (2014) examined only one wind farm, which was the first industrial wind farm constructed in the province. The host municipality chose to have this wind farm constructed, and at the time there were relatively few concerns expressed locally regarding potential impacts of wind turbines. The lack of significant impacts on property values surrounding this wind farm is consistent with the results of the current study for unopposed municipalities. Second, the time periods examined by the two studies differ, as the current study includes sales up to 2013, while the study period of Vyn and McCullough (2014) extends only to 2010. As such, the current study includes more of the time period during which public attention and controversy regarding this issue increased substantially in the province. Given the increasing opposition that has occurred over time, it may be the case that general attitudes toward wind energy as well as perceptions of the potential impacts on property values have changed in the province since the construction of the wind farm studied by Vyn and McCullough (2014), which may also contribute to the difference in results.

These differences between the two studies provide further support to the argument that the setting plays an important role in the nature of observed property value impacts of wind turbines. In addition, it is evident from the results of the analysis comparing impacts in opposed municipalities and unopposed municipalities that the nature of turbine impacts varies across jurisdictions, even within the same province. Hence, for jurisdictions considering wind energy development that are concerned about property value impacts, an assessment of prevailing attitudes toward wind energy within the jurisdiction may provide an indication of whether property values will be significantly impacted by future wind facilities.

Acknowledgments

This paper is based, in part, on data provided by the Municipal Property Assessment Corporation. Any opinions, findings, conclusions, or recommendations expressed in this material are those solely of the author and are not necessarily the views of the Municipal Property Assessment Corporation.

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EXHIBIT
27

Correction

ECOLOGY, SUSTAINABILITY SCIENCE

Correction for "Solar energy development impacts on land cover change and protected areas," by Rebecca R. Hernandez, Madison K. Hoffacker, Michelle L. Murphy-Mariscal, Grace C. Wu, and Michael F. Allen, which appeared in issue 44, November 3, 2015, of *Proc Natl Acad Sci USA* (112:13579–13584; first published October 19, 2015; 10.1073/pnas.1517656112).

The authors note that on page 13579, right column, first full paragraph, lines 12–16, the following statement published incorrectly: "If up to 500 GW of USSE may be required to meet United States-wide reduction of 80% of 1990 greenhouse gas emissions by 2050, 71,428 km^2 of land may be required (roughly the land area of the state of South Carolina) assuming a capacity factor of 0.20 (an average capacity factor for PV; Table S1)." The statement should instead appear as: "For example, up to 500 GW of USSE may be required to meet United States-wide reduction of 80% of 1990 greenhouse gas emissions by 2050 (33). This requires about 14,285 km^2 of land [roughly the area of the state of Connecticut, (9)], underscoring the possible vast area requirements for energy needs in the United States." Additionally, the authors note ref. 33 was omitted from the published article. The full reference appears below.

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www.pnas.org/cgi/doi/10.1073/pnas.1602975113

Solar energy development impacts on land cover change and protected areas

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Edited by B. L. Turner, Arizona State University, Tempe, AZ, and approved September 16, 2015 (received for review September 4, 2015)

Decisions determining the use of land for energy are of exigent concern as land scarcity, the need for ecosystem services, and demands for energy generation have concomitantly increased globally. Utility-scale solar energy (USSE) [i.e., ≥1 megawatt (MW)] development requires large quantities of space and land; however, studies quantifying the effect of USSE on land cover change and protected areas are limited. We assessed siting impacts of >160 USSE installations by technology type [photovoltaic (PV) vs. concentrating solar power (CSP)], area (in square kilometers), and capacity (in MW) within the global solar hot spot of the state of California (United States). Additionally, we used the Carnegie Energy and Environmental Compatibility model, a multiple criteria model, to quantify each installation according to environmental and technical compatibility. Last, we evaluated installations according to their proximity to protected areas, including inventoried roadless areas, endangered and threatened species habitat, and federally protected areas. We found the plurality of USSE (6,995 MW) in California is sited in shrublands and scrublands, comprising 375 km^2 of land cover change. Twenty-eight percent of USSE installations are located in croplands and pastures, comprising 155 km^2 of change. Less than 15% of USSE installations are sited in "Compatible" areas. The majority of "Incompatible" USSE power plants are sited far from existing transmission infrastructure, and all USSE installations average at most 7 and 5 km from protected areas, for PV and CSP, respectively. Where energy, food, and conservation goals intersect, environmental compatibility can be achieved when resource opportunities, constraints, and trade-offs are integrated into siting decisions.

concentrating solar power | conservation | greenhouse gas emissions | land use | photovoltaics

The need to mitigate climate change, safeguard energy security, and increase the sustainability of human activities is prompting the need for a rapid transition from carbon-intensive fuels to renewable energy (1). Among renewable energy systems, solar energy has one of the greatest climate change mitigation potentials with life cycle emissions as low as 14 g CO_2-eq·kW·h^{-1} [compare this to 608 g CO_2-eq·kW·h^{-1} for natural gas (2)]. Solar energy embodies diverse technologies able to capture the sun's thermal energy, such as concentrating solar power (CSP) systems, and photons using photovoltaics (PV). In general, CSP is economically optimal where direct normal irradiance (DNI) is 6 kW·h·m^{-2}·d^{-1} or greater, whereas PV, able to use both diffuse and DNI, is economically optimal where such solar resources are 4 kW·h·m^{-2}·d^{-1} or greater. Solar energy systems are highly modular ranging from small-scale deployments (≤1 MW; e.g., residential rooftop modules, portable battlefield systems, solar water heaters) to centralized, utility-scale solar energy (USSE) installations (≥1 MW) where a large economy of scale can meet greater energy demands. Nonetheless, the diffuse nature of solar energy necessitates that large swaths of space or land be used to collect and concentrate solar energy into forms usable for human consumption, increasing concern over potential adverse impacts on natural ecosystems, their services, and biodiversity therein (2–5).

Given the wide range of siting options for USSE projects, maximizing land use efficiency and minimizing land cover change is a growing environmental challenge (6–8). Land use efficiency describes how much power or energy a system generates by area (e.g., watts per square meter, watt-hours per square meter, respectively). For example, USSE installations have an average land use efficiency of 35 W·m^{-2} based on nameplate capacity under ideal conditions (9). The ratio of the realized generation of an installation to maximum generation under ideal conditions over a period is the capacity factor. Using these two terms, we can quantify land requirements for USSE at larger spatial scales. If up to 500 GW of USSE may be required to meet United States-wide reduction of 80% of 1990 greenhouse gas emissions by 2050, 71,428 km^2 of land may be required (roughly the land area of the state of South Carolina) assuming a capacity factor of 0.20 (an average capacity factor for PV; Table S1). This underscores the possible vast area requirements for meeting energy needs in the United States and elsewhere. Increasing the land use efficiency of each installation—e.g., decreasing space between rows of PV modules or CSP mirrors—and prudent siting decisions that incorporate the weighting of environmental trade-offs and synergies can reduce land cover change impacts broadly (10).

Land cover change owing to solar energy has received increasing attention over concerns related to conflicts with biodiversity goals (2–4) and greenhouse gas emissions, which are released when

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Significance

Decisions humans make about how much land to use, where, and for what end use, can inform innovation and policies directing sustainable pathways of land use for energy. Using the state of California (United States) as a model system, our study shows that the majority of utility-scale solar energy (USSE) installations are sited in natural environments, namely shrublands and scrublands, and agricultural land cover types, and near (<10 km) protected areas. "Compatible" (≤15%) USSE installations are sited in developed areas, whereas "Incompatible" installations (19%) are classified as such owing to, predominantly, lengthier distances to existing transmission. Our results suggest a dynamic landscape where land for energy, food, and conservation goals overlap and where environmental cobenefit opportunities should be explored.

Author contributions: R.R.H. designed research; R.R.H. and M.K.H. performed research; R.R.H. and M.K.H. contributed new reagents/analytic tools; R.R.H. and M.K.H. analyzed data; and R.R.H., M.K.H., M.L.M.-M., G.C.W., and M.F.A. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1517656112/-/DCSupplemental.

biomass, including soil, is disturbed or removed during the lifetime of a power plant (11, 12). Siting USSE installations in places already impacted by humans (e.g., parking lots, rooftops) reduces the likelihood that adverse environmental impacts will occur and can exceed generation demands for renewable energy goals in places with moderate- to high-quality solar resources (8, 10, 13), including California. When sites within the built environment are inaccessible, siting that minimizes land use and land cover change within areas acting as carbon sinks, avoids extirpation of biodiversity, and does not obstruct the flow of ecosystem services to residents, firms, and communities, can serve to mitigate adverse environmental impacts (2, 3, 9, 10, 14, 15). Siting within the built environment also reduces the need for complex decision making dictating the use of land for food or energy (16).

Recent studies have underscored the role that proximity of threats to protected areas plays in meeting conservation goals (16–20). Protected areas may preclude habitat loss within boundaries; however, a prevailing cause of degradation within protected areas is land use and land cover change in surrounding areas. Specifically, protected areas are effective when land use nearby does not obstruct corridor use, dispersion capabilities, nor facilitate invasions of nonnative species through habitat loss, fragmentation, and isolation—including those caused by renewable energy development. Quantifying both internal and external threats is necessary for assessing vulnerability of individual protected areas to conversion and landscape sustainability overall. Siting decisions can be optimized with decision support tools (10, 14) that differentiate areas where direct (e.g., land cover change) and proximate effects (e.g., habitat fragmentation) are lowest on the landscape.

Several studies have made predictions regarding which specific land cover types may be impacted by solar energy development (7, 21); however, few studies have evaluated actual siting decisions and their potential or realized impact on land cover change (9, 11). In this study, our objectives were to (*i*) evaluate potential land cover change owing to development of utility-scale PV and CSP within the state of California (United States) and describe relationships among land cover type and the number of installations, capacity, and technology type of USSE; (*ii*) use the decision support tool, the Carnegie Energy and Environmental Compatibility (CEEC) model (10), to develop a three-tiered spatial environmental and technical compatibility index (hereafter called Compatibility Index; "Compatible," "Potentially Compatible," and "Incompatible") for California that identifies environmentally low-conflict areas using resource constraints and opportunities; and (*iii*) compare utility-scale PV and CSP installation locations with the Compatibility Index and their proximity to protected areas to quantify solar energy development decisions and their impact on land cover change (see *Supporting Information* for details).

We selected the state of California as a model system owing to its relatively early, rapid, and ambitious deployment of solar energy systems, 400,000 km^2 of land area (greater than Germany and 188 other countries), large human population and energy demands, diverse ecosystems comprising 90% of the California Floristic Province biodiversity hot spot, and its long-standing use in elucidating the interrelationship between land and energy (9, 10, 22, 23).

Results

We identified 161 planned, under construction, and operating USSE installations throughout 10 land cover types (Figs. 1 and 2) among 16 total in the state of California (Table S2). Broadly, PV installations are concentrated particularly in the Central Valley and the interior of southern California, whereas CSP power plants are sited exclusively in inland southern California (Figs. 1 and 2). For all technology types, the plurality of capacity (6,995 MW) is found in shrubland and scrubland land cover type,

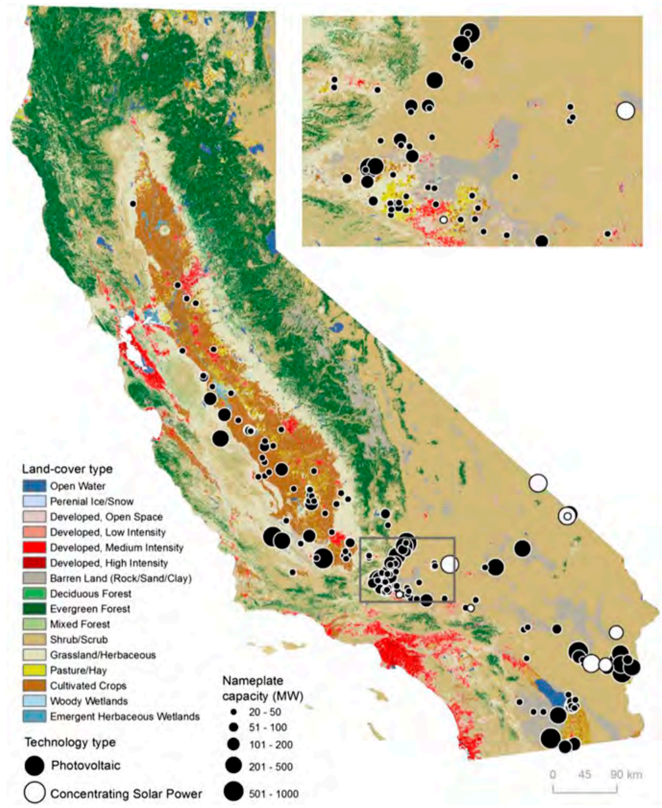

Fig. 1. Map showing land cover types across California and the size and location of USSE installations.

necessitating 375 km^2 of land (Table 1). This area is approximately two times greater than USSE development occurring within cultivated croplands, representing 4,103 MW of capacity within 118 km^2. Over 2,000 MW of existing or proposed USSE capacity is sited within the built environment, particularly within relatively lower density areas.

PV power plants are found in 10 land cover types; the plurality of capacity is sited within shrubland/scrublands (6,251 MW; Table 1), representing 26.0% of all PV installations (Fig. 2). Capacity for utility-scale PV installations is also represented within cultivated croplands (3,823 MW), barren land (2,102 MW), developed (2,039 MW), and grassland/herbaceous (1,483 MW) land cover types. Within the developed land cover types, open space is most used (1,205 MW) for utility-scale PV capacity. For CSP, 1,000 MW are located within 34 km^2 of barren land land cover types, and conjointly within shrubland/scrublands (744 MW, 32 km^2).

Using the decision support tool, CEEC (Fig. 3), we identified 22,028 and 77,761 km^2 of Compatible and Potentially Compatible area, respectively, in California for developing PV (Fig. S1). Generation-based potential within Compatible areas—comprising 5.4% of California's area—is 8,565 TW·h·y^{-1} for fixed-tilt modules and up to 11,744 TW·h·y^{-1} for dual-axis modules. For CSP technologies, we found 6,274 and 33,489 km^2 of Compatible and Potentially Compatible area. Generation-based potential for CSP within Compatible areas—comprising 1.5% of California's area—is 5,947 TW·h·y^{-1}.

USSE installations vary in the environmental compatibility of their actual or proposed site (Fig. 4 *A* and *B*). The majority (71.7%) of PV USSE installations are in Potentially Compatible areas, whereas 11.2% are located in Compatible areas. PV installations classified as Incompatible are due to distances from existing transmission infrastructure exceeding 10 km (45.9%), slope exceeding the recommended threshold (41.9%), and to a

Table 1. USSE installations and land cover type

Land cover type	Nameplate capacity, MWdc PV	%	CSP	%	Area, km^2 PV	%	CSP	%
Barren land (rock/sand/clay)	2,102	12	**1,000**	**48**	77	11	**34**	**45**
Cultivated crops	3,823	22	280	14	110	15	8	11
Developed (all)	2,039	12	50	2	70	10	1	1
Developed, high intensity	50	0	0	0	1	0	0	0
Developed, medium intensity	624	4	0	0	17	2	0	0
Developed, low intensity	160	1	0	0	9	1	0	0
Developed, open space	1,205	7	50	2	43	6	1	1
Emergent herbaceous wetlands	60	0	0	0	1	0	0	0
Grass/herbaceous	1,483	9	0	0	72	10	0	0
Pasture/hay	1,397	8	0	0	37	5	0	0
Shrubland/scrubland	**6,251**	**36**	744	36	**343**	**48**	32	43

The nameplate capacity [in megawatts (MWdc)], footprint (in square kilometers), and number of photovoltaic (PV) and concentrating solar power (CSP) USSE installations (>20 MW) in California (in planning, under construction, operating) by land cover type. Bold data represent the greatest value among all land cover types.

lesser degree, owing to development on endangered and threatened species habitat (9.7%) and federally preserved land (3.2%; Fig. 4 *A* and *B*). For CSP installations, 55.5% are located in either Compatible or Potentially Compatible areas. Siting incompatibilities for CSP were either due to slope (25.0%) or distance from transmission lines (75.0%). PV and CSP installations on Compatible areas range in capacity between 20 and 200 MW, and are located within the Central Valley and inland southern California regions, excepting one PV facility in Yolo County (Fig. 4*A*). PV facilities on Incompatible land are found throughout all of California and, excepting one facility (250 MW; San Luis Obispo County), are 200 MW in capacity or less.

PV and CSP USSE installations average 7.2 ± 0.9 and 5.3 ± 2.3 km, respectively, from the closest protected area (Fig. 5). Federally protected areas are the nearest protected area type (7.8 ± 1.0) to land use and land cover change for PV development, whereas both endangered and threatened species habitat (5.7 ± 2.4) and federally protected areas (5.3 ± 2.3) are nearest for CSP development. Of PV installations, 73.7% were less than 10 km and 47.4% were less than 5 km away from the nearest protected area. Of CSP installations, 90.0% were less than 10 km away and 60.0% were less than 5 km away from the nearest protected area.

Discussion

Evaluation of siting decisions for USSE is increasingly relevant in a world of mounting land scarcity and in which siting decisions are as diverse as their deployment worldwide. For example, China has emphasized utility-scale, ground-mounted PV and residential, small-scale solar water heating installations (24), whereas Germany is notable for achieving up to 90% development within the built environment (25). In California, a large portion of USSE installations is sited far from existing transmission infrastructure. New transmission extensions are expensive, difficult to site due to social and environmental concerns, and require many years of planning and construction. Such transmission-related siting incompatibilities not only necessitate additional land cover change but also stand in the way of cost-efficient and rapid renewable energy deployment.

Environmental regulations and laws, which vary drastically from one administrative area to the next, may also cause incongruities in siting decisions. Inherent ambiguities of such policies allows for further inconsistencies. A study in southern Italy (11) found that two-thirds of authorizations for USSE were within environmentally "unsuitable" areas as defined by municipal and international criteria (e.g., United Nations Educational, Scientific and Cultural Organization sites), with adverse implications for land cover change-related CO_2 emissions. Studies (7, 21) including our own reveal that regulations and policies to date have deemphasized USSE development in California, the United States, and North America, respectively, within the built environment and near population centers in favor of development within shrublands and scrublands. California's shrublands and scrublands comprise, in part, the California Floristic Province, a biodiversity hot spot known for high levels of species richness and endemism and where 70% or more of the original extent of vegetation has been lost due to global environmental change-type threats, including land cover change (26, 27). In biologically rich areas like this, land cover change has the potential to greatly impact ecological value and function. Globally, the extent of shrubland and scrubland is vast; therefore, in areas where biodiversity is low, goods and services of shrublands may include diverse recreational opportunities, culturally and historically significant landscapes, movement corridors for wildlife, groundwater as a drinking source, and carbon (sequestration), which may also be adversely impacted by land cover conversion (28).

Proximity impacts result from the fragmentation and degradation of land near and between protected areas, reducing ecological flows of energy, organisms, and goods (16–20). In a study of 57

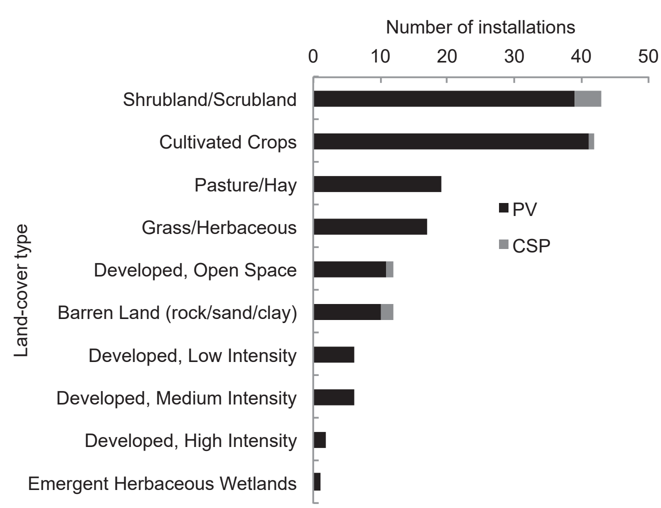

Fig. 2. Number of photovoltaic (PV) and concentrating solar power (CSP) installations (planned, under construction, operating) by land cover type in California; represented in order of most installations to least for both technologies.

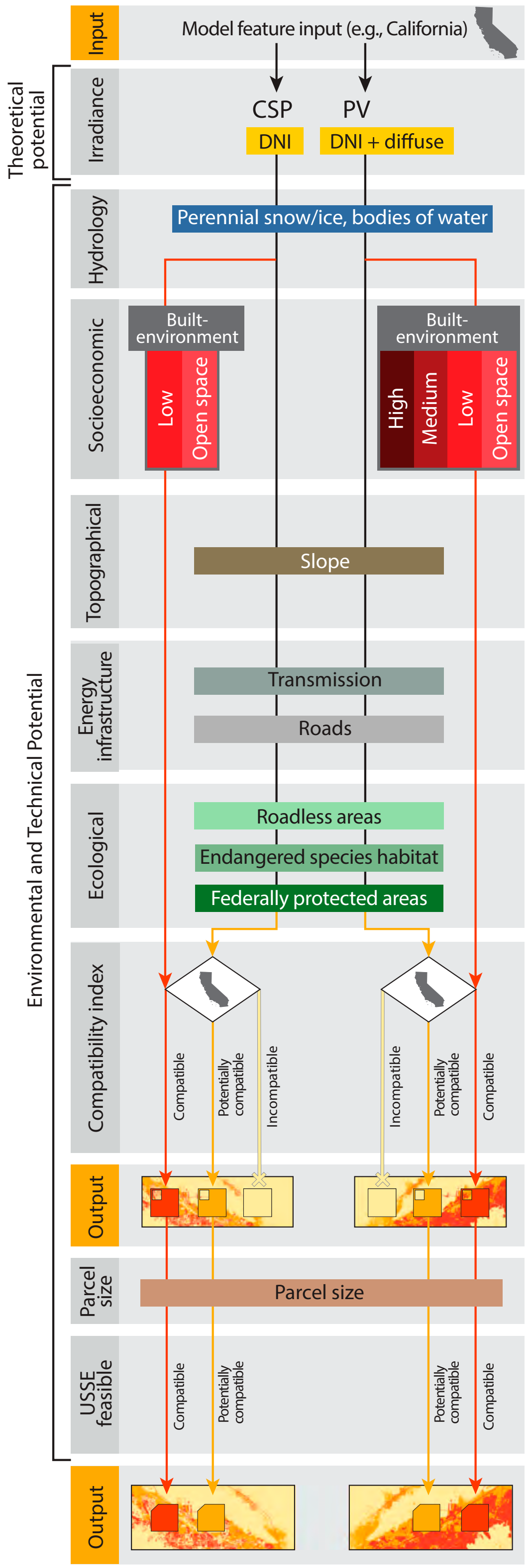

Fig. 3. Workflow of the Carnegie Energy and Environmental Compatibility (CEEC) model, a decision support tool, showing model inputs (resource opportunities and constraints), Environmental and Technical Compatibility Index, and model outputs.

US protected areas, Hansen et al. (16) found such zones extended an average of 18 times (in area) beyond the park area (e.g., Mojave National Preserve, three times protected area, i.e., ∼30 km radially beyond preserve boundary). Additionally, Hamilton et al. (17) used distances of 5, 25, and 75 km from all US protected area boundaries to represent three spatial scales (i.e., buffers) of proximity impacts owing to US land cover and land use change. Last, the US Fish and Wildlife Service's Partners for Fish and Wildlife Program, seeks to reduce adverse proximity impacts by augmenting protected areas with private land restoration, targeting land within a maximum distance of 75 km from existing protected areas. Thus, our results confirm USSE development in California engenders important proximity impacts, for example, encompassing all three spatial scales from Hamilton et al. (17) and decreasing land available for US Fish and Wildlife Service partner restoration programs.

Industrial sectors—including energy and agriculture—are increasingly responsible for decisions affecting biodiversity. Concomitantly, target-driven conservation planning metrics (e.g., percentage of remaining extant habitat does not fall below 40%), geospatial products (e.g., decision support tools), and the monetization of carbon and ecosystem services are increasing and may be effective in compensating for the lack of target-driven regulation observed in policy (29).

Last, development decisions may overlook environmental resources unprotected by policies but valued by interest groups [e.g., important bird areas, essential connectivity areas, vulnerability of caliche (i.e., mineralized carbon) in desert soils, biodiversity hot spots, percent habitat loss]. Several elements of the environment providing ecosystem services that humans depend upon remain widely unprotected by laws and regulations and vastly understudied. By integrating land conservation value earlier in the electricity procurement and planning process, preemptive transmission upgrades or expansions to low-impact regions could improve the incentive to develop in designated zones, avoiding future incompatible development. However, zones themselves must also be carefully designated. The landscape-scale Desert Renewable Energy Conservation Plan initially provided a siting framework—including incidental take authorizations of endangered and threatened species—for streamlining solar energy development within the 91,000 km^2 of mostly desert habitat in public and private lands and designated as the Development Focus Area (DFA). After accounting for unprotected environmental attributes like biodiversity, Cameron et al. (14) identified ∼7,400 km^2 of relatively low-value conservation land within the Mojave Desert Ecoregion (United States) that can meet California's 33% renewable portfolio standard for electricity sales seven times over. Since this publication, the Desert Renewable Energy Conservation Plan's DFA has now been restricted to only public lands, which some argue to be more intact, and to the ire of certain local interest groups and government agencies. Hernandez et al. (10) developed a satellite-based decision support tool, the CEEC model, that showed that generation-based technical potential of PV and CSP within the built environment could meet California's total energy demand 4.8 and 2.7 times over, respectively. Development decisions may also overlook synergistic environmental cobenefit opportunities. Environmental cobenefit opportunities include the utilization of degraded or contaminated lands, colocation of solar and agriculture, hybrid power systems, and building-integrated PV (2).

This study found that nearly 30% of all USSE installations are sited in croplands and pastures; signifying perhaps an increasing affinity for using agricultural lands for renewable energy, specifically within the Central Valley of California, renowned for agricultural productivity globally. The growing demand for food, affordable housing, water, and electricity puts considerable pressure on available land resources, making recent land use decisions in this region a noteworthy case study for understanding the food–energy–water nexus that should be explored. Opportunities to minimize land use change include colocating renewable energy systems with food production and converting degraded and salt-contaminated lands, unsuitable for agriculture, to sites for

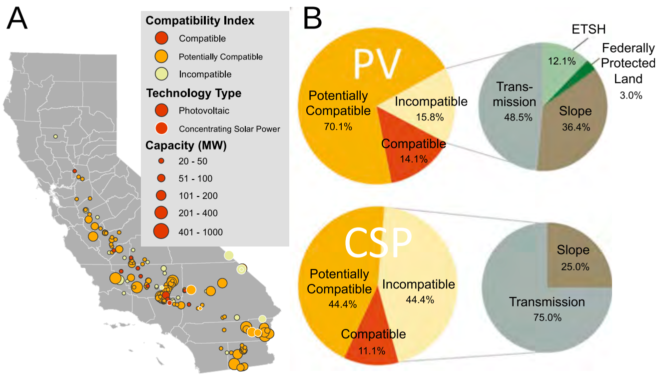

Fig. 4. (*A*) Map of California showing utility-scale solar energy (USSE) (planned, under construction, operating) installations' compatibility by technology [i.e., photovoltaic (PV), concentrating solar power (CSP)], site, and capacity (in megawatts). (*B*) Percentage of USSE installations sited in Compatible, Potentially Compatible, and Incompatible areas. For USSE installations in incompatible sites, we provide the percentage of each incompatibility type.

renewable energy production. Using unoccupied spaces such as adjacent to and on top of barns, parking lots, and distribution centers in agricultural areas is another win–win scenario. In sub-Saharan Africa, integrating solar energy into a drip irrigation system has enhanced food security by conserving water, enhancing reliability of power, and conserving land and space (30). As the development of renewable energy and the production of food are expected to grow, so will the need to understand and evaluate their interactions with the land supporting this expansion in other landscapes.

Conclusion

A growing body of studies underscores the vast potential of solar energy development in places that minimize adverse environmental impacts and confer environmental cobenefits (2, 10, 14, 15, 21). Our study of California reveals that USSE development is a source of land cover change and, based on its proximity to protected areas, may exacerbate habitat fragmentation resulting in direct and indirect ecological consequences. These impacts may include increased isolation and nonnative species invasions, and compromised movement potential of species tracking habitat shifts in response to environmental disturbances, such as climate change. Furthermore, we have shown that USSE development within California comprises siting decisions that lead to the alteration of natural ecosystems within and close to protected areas in lieu of land already impacted by humans (7, 21). Land use policies and electricity planning that emphasizes the use of human-impacted places, complies with existing environmental regulations at the federal, state, and municipal level, and considers environmental concerns over local resource constraints and opportunities, including those of communities, firms, and residents, may prove an effective approach for avoiding deleterious land cover change. Empirical analyses using decision support tools, like CEEC, can help guide development practices toward greater environmental compatibility through improved understanding of the impacts of policy and regulatory processes to date.

Methods

To achieve our objectives, we (*i*) created a multiinstitution dataset of 161 USSE installations in the state of California and compared these data to land cover data; (*ii*) developed a spatial Compatibility Index (i.e., Compatible, Potentially Compatible, and Incompatible) for California using the CEEC model that identifies environmentally low-conflict areas for development, integrating environmental and technical resource constraints and opportunities; (*iii*) compared USSE installation locations with the Compatibility Index to enumerate the number of installations sited within each area type; and (*iv*) compared USSE installation locations with their proximity to protected areas, including Inventoried Roadless Areas, Endangered and Threatened Species Habitat, and Federally Protected Areas (*Supporting Information*). All analyses were conducted using ArcGIS (10.x) and R (R: A Language and Environment for Statistical Computing).

To evaluate land cover change owing to USSE development, we collected data on PV and CSP USSE installations in California that vary in development stage (i.e., planned, under construction, operating) and range in nameplate capacity, selecting a subset of all USSE that range from 20 to 873 MW, 20 MW being a legislative capacity threshold for transmission connection affecting development action. Data for each installation included nameplate capacity under standard test conditions (in megawatts), land footprint (in square kilometers), technology type, and point location (latitude, longitude). Data were collected exclusively from official government documents and records (see *Supporting Information* for details). We define the land footprint as the area directly affected during the construction, operation, and decommissioning phases of the entire power plant facility, excluding existing transmission corridors, land needed for raw material acquisition, and land for generation of energy required for manufacturing. Installations that did not meet data quality criteria (e.g., lacking exact location) were excluded, resulting in a total of 161 USSE installations (see *Supporting Information* for details). Data were collected beginning in 2010 and updated until May 2014. Installations in our dataset vary in their development stage and therefore include installations that may change in attribute or may never reach full operation. Given that we are interested in decisions regarding siting, we included siting data for planned installations, despite their potential uncertainty, as these reflect the most current siting practices that may not be fully represented in decisions for installations that are already under construction or operating.

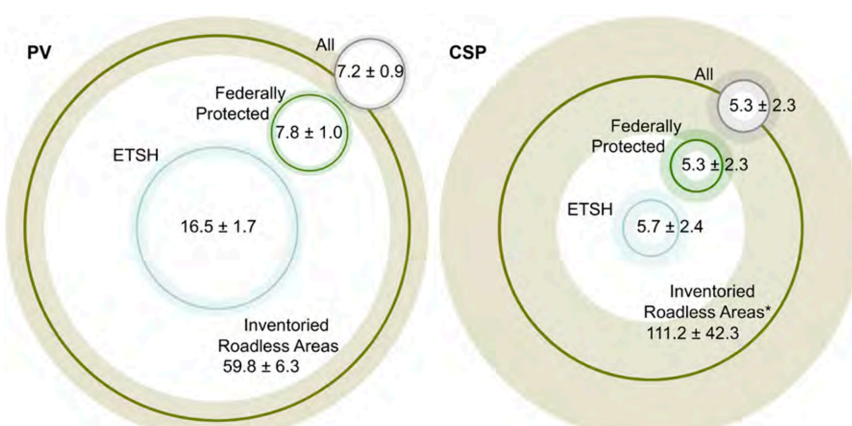

Fig. 5. Proximity of PV and CSP USSE installations to Endangered and Threatened Species Habitat, Federally Protected Areas, Inventoried Roadless Areas, and the closest for all protected area types. Circles are to scale, relatively (with the exception of Inventoried Roadless Areas for CSP), showing 95% confidence intervals (shaded area).

To evaluate land cover change by USSE development, we compared the point location of each USSE power plant from our dataset (by their latitude and longitude) to the land cover type according to the National Land Cover Dataset (NLCD) (30-m resolution) and allocated the reported total footprint of the installation as land cover change within this land cover type. All 16 land cover types, as described by the NLCD, are represented in California, including developed areas within the built environment (Table S3). Developed areas are further classified according to imperviousness of surfaces: open-space developed (<20% disturbed surface cover; e.g., large-lot single-family housing units, golf courses, parks), low-intensity developed (20–49% disturbed cover), medium-intensity developed (50–79% disturbed cover), and high-intensity developed (80–100% disturbed cover; e.g., apartment complexes, row houses, commercial and industrial facilities).

The CEEC model (10) is a decision support tool used to calculate the technical potential of solar electricity generation and characterize site suitability by incorporating user-specified resource opportunities and constraints (Fig. 3 and Tables S2–S5). The CEEC model uses the National Renewable Energy Laboratory's satellite-based diffuse/direct normal radiation and direct normal radiation models, which estimate average daily insolation (in kilowatt-hours per square meter per day) over 0.1° surface cells (~10 km in size), to identify areas with annual average solar resources adequate for PV ($\geq$4 $kW{\cdot}h{\cdot}m^{-2}{\cdot}d^{-1}$) and CSP ($\geq$6 $kW{\cdot}h{\cdot}m^{-2}{\cdot}d^{-1}$) technologies, respectively (Table S1).

Among these areas, bodies of open water and perennial ice and snow were excluded as potential sites. We indexed the resulting area for solar energy infrastructure—independently for PV and CSP—as follows: Compatible, Potentially Compatible, and Incompatible (*Supporting Information*). Because solar energy potential within California's developed areas can meet the state's current energy consumptive demand 2.7 times over, decrease or eliminate land cover change, and reduce environmental impacts (10), we defined all four developed land cover classes as Compatible, excepting CSP in high and medium intensity as, to date, CSP technologies have not been deployed there owing to the relatively lower modularity of CSP.

Potentially Compatible areas augment site selections beyond Compatible areas. As slopes of 3% and 5% or less are most suitable for CSP and PV installations, respectively—owing to reduced costs and impact associated with surface grading—we used the National Elevation Dataset (varies from 3- to 30-m resolution; US Geological Survey) to exclude areas without these criteria. To minimize costs and impacts linked to new construction activities and materials, Potentially Compatible areas were also restricted to areas within 10 and 5 km of transmission lines (California Energy Commission) and roads (TIGER), respectively (*Supporting Information*, Fig. 3, and Table S4). We excluded areas where road construction is prohibited ("Federal Roadless Areas"; US Department of Forest and Agriculture), critical habitat of threatened and endangered species (US Fish and Wildlife Service), and federally protected areas (i.e., GAP Statuses 1 and 2, Protected Areas Database of the United States, US Geological Survey; Table S1). We reported generation-based potential for PV and CSP at the utility-scale, i.e., within areas identified as Compatible and Potentially Compatible and within areas meeting a minimum parcel size as needed for a 1-MW installation. Incompatible areas are not classified as Compatible and Potentially Compatible areas. To quantify impacts of solar energy development decisions, we spatially characterized the number, capacity, technology type, and footprint of USSE power plants dataset within the Compatibility Index and analyzed the reasons for incompatibility.

To quantify impact of proximity to protected areas from USSE development, we calculated the distance between each USSE facility data point (by technology type) to the nearest protected area by type (i.e., inventoried roadless areas, critical habitat of threatened and endangered species, and federally protected areas) using the "Near (Analysis)" in ArcGIS, and subsequently calculated the average of all distances (by protected area type) and 95% confidence intervals. For "all" protected area types, we used the shortest distance between each USSE facility data point and the three protected area types, and subsequently calculated the average of these shortest distances and 95% confidence intervals.

ACKNOWLEDGMENTS. We thank Morvarid Tavassoli, who assisted with data collection, and Noemi Alvarez, who assisted with spatial analyses. We thank Leslie White, who contributed to graphic design. The McGee Research Grant of the Stanford's School of Earth Sciences, the TomKat Center for Sustainable Energy, the Jean Langenheim Research Fellowship of Graduate Women in Science Society, the Hispanic Scholarship Fund's William Randolph Hearst Fund Scholarship, and the Vice Provost Office of Graduate Education's Diversifying Academia, Recruiting Excellence Program, provided funding for this study.

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EXHIBIT
28

Environmental Science & Technology

Article

Cite This: Environ. Sci. Technol. 2017, 51, 14472–14482

pubs.acs.org/est

Land-Sparing Opportunities for Solar Energy Development in Agricultural Landscapes: A Case Study of the Great Central Valley, CA, United States

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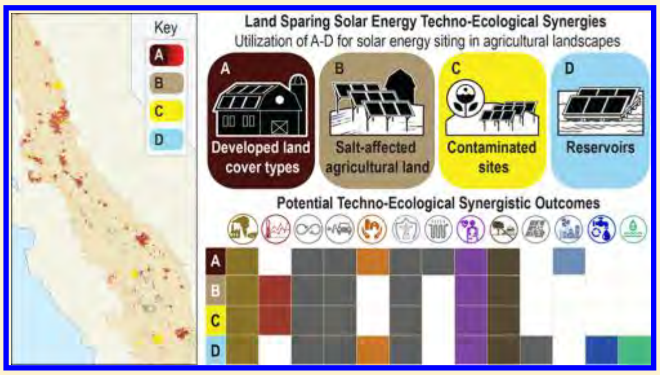
Supporting Information

ABSTRACT: Land-cover change from energy development, including solar energy, presents trade-offs for land used for the production of food and the conservation of ecosystems. Solar energy plays a critical role in contributing to the alternative energy mix to mitigate climate change and meet policy milestones; however, the extent that solar energy development on nonconventional surfaces can mitigate land scarcity is understudied. Here, we evaluate the land sparing potential of solar energy development across four nonconventional land-cover types: the built environment, salt-affected land, contaminated land, and water reservoirs (as floatovoltaics), within the Great Central Valley (CV, CA), a globally significant agricultural region where land for food production, urban development, and conservation collide. Furthermore, we calculate the technical potential (TWh year^{-1}) of these land sparing sites and test the degree to which projected electricity needs for the state of California can be met therein. In total, the CV encompasses 15% of CA, 8415 km^2 of which was identified as potentially land-sparing for solar energy development. These areas comprise a capacity-based energy potential of at least 17 348 TWh year^{-1} for photovoltaic (PV) and 2213 TWh year^{-1} for concentrating solar power (CSP). Accounting for technology efficiencies, this exceeds California's 2025 projected electricity demands up to 13 and 2 times for PV and CSP, respectively. Our study underscores the potential of strategic renewable energy siting to mitigate environmental trade-offs typically coupled with energy sprawl in agricultural landscapes.



■ INTRODUCTION

In the 21st century, agricultural landscapes are a complex nexus in which land, energy, and water are increasingly limited and interconnected.[1−4] Food production is intrinsically dependent on the diminishing supply of fresh water and viable land.[5,6] The pumping of water for irrigation, dependent on declining aquifers,[7] and other agricultural activities necessitates vast amounts of energy.[8] In the United States, the most agriculturally productive country globally, expenses related to energy (e.g., fertilizer production and equipment manufacture and use) are one of the primary limitations of food production, while U.S. dependency on foreign energy imports imposes additional limitations.[4] Additionally, organic emissions and those from carbon-intensive energy sources pose serious health and environmental risks to farming communities and geographically nested urban population centers.[9−12] In response to such limitations and risks,[4] solar energy is increasingly adopted by farmers and other agricultural stakeholders in ways that may spare land (e.g., building integrated photovoltaics [PVs]) for food and fiber production or, conversely, place additional pressure on arable land by displacing such land for energy production.[13,14]

Unlike conventional energy sources, solar energy can be integrated into pre-existing agricultural infrastructure and under-utilized spaces without adversely affecting commodity production or space required for such activities (e.g., edges of fields, corners of center pivot irrigation fields, and barn rooftops).[13,15,16] Farms require energy to support machinery, electric fencing, pumping and water filtration for irrigation,

Received: October 3, 2017
Revised: November 18, 2017
Accepted: November 29, 2017
Published: December 19, 2017

DOI: 10.1021/acs.est.7b05110
Environ. Sci. Technol. 2017, 51, 14472−14482

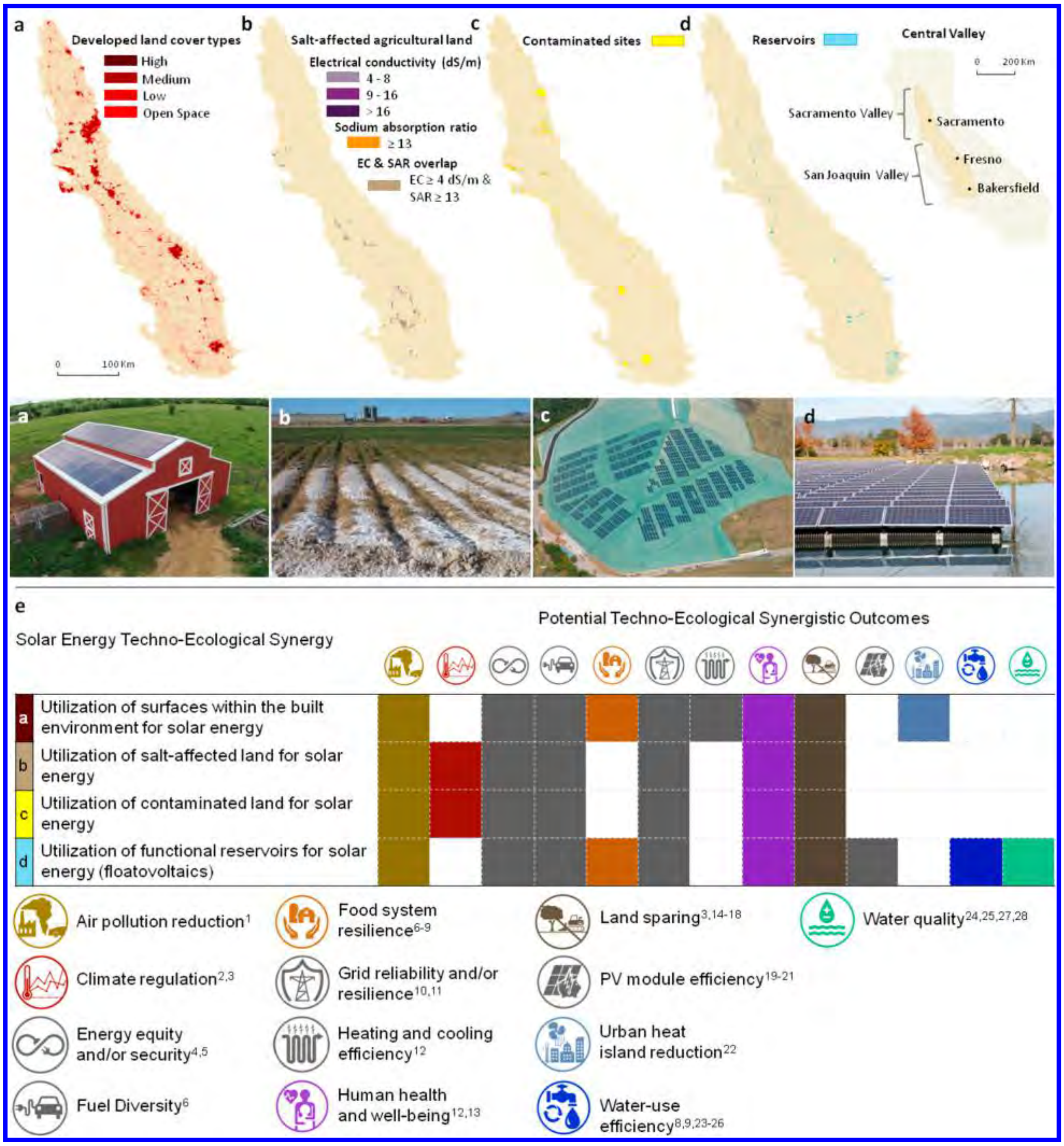


Figure 1. Land sparing solar energy siting opportunities within a 21st century agricultural landscape, i.e., California's Central Valley including within and over (a) the built environment, (b) salt-affected soils, (c) contaminated land, and (d) reservoirs. Contaminated sites are shown accurately according to their actual area but not shape. We posit that these land-sparing siting opportunities for solar energy development may also function individually (e) as a techno-ecological synergy (TES), a framework for engineering mutually beneficial relationships between technological and ecological systems that engender both techno-centric outcomes (gray icons) as well as support for sustainable flows of ecosystem goods and services (colored icons). Numbers refer to citations that provide justification for all potential techno-ecological synergistic outcomes. Larger versions of the map images are available in Figure S4. Photograph credit from left to right: (a) Cromwell Solar in Lawrence, Kansas by Aron Cromwell; (b) Donald Suarez, USDA Salinity Laboratory; (c) Carlisle Energy; (d) Far Niente Winery. All photographs are used with permission. Maps were made using ESRI ArcGIS Desktop (version 10.4) software.

drying and storing crops, lighting, powering heaters, and cooling livestock farmhouses. Previous studies have shown that on-farm solar schemes can provide farmers with reduced electricity pricing while requiring minimal water inputs (relative to other energy sources), thereby improving overall food availability and affordability.[2,13,14]

However, when large solar industrial complexes are developed on natural or prime agricultural lands, nontrivial land-use and land-cover change (LULCC) may result.[17−19] In California, Hernandez et al. (2015) found 110 km^2 of cultivated cropland and 37 km^2 of pasture was converted into use for ground-mounted utility-scale solar energy (USSE, ≥ 1 megawatt [MW]). In the municipality of Leece, Italy; De

Marco et al. (2014) found that 51% of solar energy installations greater than 20 kW in capacity (n = 42) are sited in unsuitable areas, notably natural and agricultural areas, including century-old olive grooves.[19] Reversion of a site used for solar energy generation back to agriculture is typically unlikely, complicated by long-term application of herbicides, stabilizers, gravel, chemical suppressants, and soil compaction from power plant construction and maintenance activities. Further, land lease agreements and payback periods often exceed 15 years.[20]

The sustainability of energy, food, and water resources and the preservation of natural ecosystems are determined, in part, by how efficiently humans utilize land.[21] While most research has focused on the negative environmental impacts of ground-mounted USSE installations,[17,22] there is increasing attention on the design and enterprise of solar energy that produce both technological outcomes favorable for humans (e.g., energy security and fuel diversity) and benefits supporting ecosystem goods and services, including land sparing.[23] In this study, we define land sparing as siting decisions for solar energy infrastructure that obviate the need for LULCC that may have otherwise occurred within prime agricultural land and natural environments, respectively, including intermediates between these land-cover types. We posit that this framework, known techno-ecological synergy (TES), proposed by Bakshi et al. (2015),[24] and other studies suggest that several potential techno-ecological outcomes may be concomitantly achieved when nonconventional surfaces within agricultural landscapes are used for siting solar energy. Specifically, the utilization of geographically nested (1) urban population centers, i.e., the built environment (i.e., developed areas characterized by impermeable surfaces and human occupation), (2) land with salt-affected soils, (3) contaminated land, and (4) reservoirs may serve as recipient environments for solar energy infrastructure. These sites may also confer techno-ecological outcomes necessary for meeting sustainability goals in landscapes characterized by complex, coupled human and natural systems, such as those within agricultural landscapes. We explore these potential techno-ecological outcomes first, emphasizing the critical role these recipient environments may play in land sparing, which is the focus of our analysis (Figure 1).

Built Environments for Synergistic Solar Energy Development. Modern agricultural landscapes span 40% of Earth's surface[25] and are characterized by complex, heterogeneous mosaics in which natural, agricultural, and built-up elements, infrastructure, and policies intersect.[19,26,27] Areas characterized as the built environment within agricultural landscapes have considerable potential to accommodate solar energy development: a TES that may spare land for agricultural production and conservation locally,[17,21,28] reduce urban heat island effects,[29] and enhance human health and well-being, energy efficiency, and cost savings to consumers[30] (Figure 1). In the state of California (CA), installing small solar energy technology and USSE, including photovoltaic (PV) and concentrating solar power (CSP) technologies, throughout the built environment could meet the state's projected 2020 energy needs 3 to 5 times over.[17] Integrated PV (e.g., on rooftops, vertical walls, and over parking lots) has the lowest land footprint relative to all other energy sources (0 ha [ha]/TWh/year), incurring no LULCC, thus making developed areas environmentally optimal for PV systems. Additionally, solar panels within urban areas may lower local temperatures from increased surface albedo.[29] Integrating solar energy installations within such human-dominated environments generates cost savings directly from generation but also precludes energy losses from transmission and additional construction (e.g., grading, roads, and transmission) and raw material needs (e.g., grid connections, office facilities, and concrete) required for displacive ground-mounted USSE systems. For example, innovative ways of integrating PV technology, such as panels on or alongside transportation corridors (e.g., solar road panels[31] and photovoltaic noise barriers) and clear modules replacing windows will only increase its appeal within the built environment.[15,16,32,33]

Salt-Affected Lands for Synergistic Solar Energy Development. Naturally occurring high concentrations of salt (saline soils; Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, $SO_4{}^{2-}$, and $HCO_3{}^{-}$) or sodium (sodic soils; Na^{+}, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, $HCO_3{}^{-}$, $CO_3{}^{-}$, Cl^{-}, and $SO_4{}^{2-}$) combined with poor irrigation and farming practices can lead to dramatic losses in crop yield and, in severe cases, the cessation of agricultural productivity. An excess quantity of dissolved salt or sodium minerals in soil and water inhibits food production, threatens water quality, and facilitates sedimentation problems and soil erosion. Plant growth is limited by salinity due to the osmotic effect in which excess salts (e.g., chloride [Cl^{-}] and sulfate [$SO_4{}^{2-}$]) tightly attach to water molecules, inhibiting plant roots from absorbing "available" water due to the high passage resistance of the electric current. Different salts can affect growth uniquely where plant success is dependent on both the salt compound makeup and the individual plant's tolerance. A high sodium ratio (proportion of sodium [Na^{+}] relative to calcium [Ca^{2+}] and magnesium [Mg^{2+}]) is related to soil dispersion influenced by an excess of cations (Na^{+}) attaching to clay particles causing soil swelling and expansion. Overtime, sodic soils begin to solidify and lose their structure as they fluctuate between dry and moist periods, reducing soil permeability. Salinization impacts about 19.5% (45 million ha) of irrigated land, 2.1% (32 million ha) of dryland agriculture globally,[34] and costs the United States approximately $12 billion a year.[35] Developing solar energy on salt-affected land may reduce air pollution (e.g., when substituted for carbon-intensive energy sources), while a concomitant restoration of biophysical capacity of salt-affected land (e.g., composted municipal solar waste amendments[36] and native halophytic vegetation out-planting) may support climate regulation. Techno-centric outcomes of solar energy on salt-affected land may include energy equity, fuel diversity, and grid reliability.[37−39] Heckler[40] estimates soil lost to salt degradation will continue to increase at a yearly rate of about 0.8−16%, underscoring the potential long-term opportunity of salt-affected land as a potential land-sparing TES of solar energy (Figure 1).

Contaminated Land for Synergistic Solar Energy Development. Reclaiming land to provide sustainable energy has numerous potential techno-ecological outcomes including addressing public health risks, supporting climate regulation (e.g., following reclamation activities), and mitigating air pollution when solar energy generation is substituted for carbon-intensive sources of energy (Figure 1). Contaminated lands include brownfields, federal or nonfederal superfunds, and lands identified by the Resource Conservation and Recovery Act (RCRA), the Abandoned Mine Lands Program, and the Landfill Methane Outreach Program. Brownfields are areas previously designated for industrial or commercial use in which there are remnants of hazardous substances, pollutants, or contaminants. Superfund sites involve the most severely

DOI: 10.1021/acs.est.7b05110
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hazardous wastes requiring federal or state government attention. The RCRA ensures toxic waste storage facility sites responsibly and properly treat, store, or dispose of hazardous waste where cleanup expectations and requirements are determined by individual state governments. Once responsibly reclaimed, a process typically facilitated by government efforts, the land can be repurposed for commercial or industrial development. Contaminated sites typically left idle for extended periods of time, have low economic value, and are challenging to cultivate,[41,42] none of which undermine their potential for solar energy development. Examples of toxic wastelands that have been repurposed for solar energy development projects include sites formerly involving chemical and explosive manufacturing, steel production, tar and chemical processing, geothermal heating and cooling, and garbage disposal.[43] In the United States, the RE-Powering Initiative encourages renewable energy development on contaminated lands, and since the inception of the program, 1124 MW of renewable energy capacity is produced on 171 contaminated land sites.[44]

Floatovoltaics for Synergistic Solar Energy Development. Irrigation is the largest source of water consumption globally.[45,46] Brauman et al. (2013) found extensive variability in crop water productivity within global climatic zones indicating that irrigated croplands have significant potential to be intensified (i.e., food produced [kcal] per unit of water [L]) through improved water management.[47] The siting of solar energy panels that float on the surface of water bodies, such as reservoirs and irrigation canals, may minimize evaporation, reduce algae growth, cool water temperatures, and improve energy efficiency by reducing PV temperatures through evaporative cooling (Figure 1). There are vast opportunities for floatovoltaic deployment; collectively, lakes, ponds, and impoundments (water bodies formed by dams) cover more than 3% of the earth's surface area.[48] Reservoirs allow for relatively seamless solar energy integration compared with natural bodies of water, such as rivers, because their surfaces are relatively placid. This reduces the likelihood that panels will collide with each other or drift and break apart, allowing for easy maintenance. Additionally, unlike rivers and lakes, reservoirs are often located where energy demands are relatively high. Floatovoltaics integrate well into agricultural systems by allaying competition with land resources and providing energy and water savings. Farmers increasingly rely on agricultural ponds as water storage for irrigation, livestock, and aquaculture.[48] On-farm reservoirs are often wide but shallow making them more susceptible to water loss through evaporation.[49] Algae growth, a nutrient pollutant, is another costly nuisance for irrigation ponds that can clog pumps, block filters, and produce odors,[50] conditions attributed to further water losses that can be expensive and challenging for farmers to address. Solar panels reduce light exposure and lower water temperatures, minimizing algae growth and the need to filter water.[51−53] Finally, when solar panels are placed over cool water instead of land, PV module efficiency may increase 8−10%[54] where increased thermal transfer limits resistance on the circuit allow the electrical current to move faster.[55,56]

The Central Valley: A Model System for Land-Energy Interactions. The Central Valley (CV) is an ideal region in which to study land sparing benefits of solar energy TESs and to inform on broader issues related to the intersection between energy and land.[57] Located in one of the world's five mediterranean climate regions, California is valued as the largest agricultural producer within the United States, responsible for over half of the country's fruits and nuts, and is productive year-round.[58,59] This region also includes, in part, the California Floristic Province, an area supporting high concentrations of native and endemic species.[60] Over the last 150 years, the CV has experienced expansive LULCC owing to agricultural and urban development, which has accelerated habitat loss and fragmentation in areas of native prairies, marshes, vernal pools, oak woodlands, and alkali sink scrublands.[61] Within the last 30 years, LULCC has also occurred within agricultural land owing to energy development and urbanization, a large percent of which were considered prime farmlands.[61]

To date, there are few studies assessing the potential of solar energy within agricultural landscapes in ways that may concomitantly facilitate synergistic outcomes on technological and ecological systems beyond avoided emissions.[62,63] In this study, we sought to (1) evaluate the land sparing potential of solar energy development across four nonconventional land-cover types: the built environment, salt-affected land, contaminated land, and water reservoirs, as floatovoltaics, within the Great Central Valley (CV, CA) and (2) quantify the theoretical and technical (i.e., generation-based) potential of PV and CSP technologies within the CV and across these potential solar energy TESs to determine where technical potential for development is greatest geographically. Further, we sought to (3) determine the spatial relationship of land sparing areas with natural areas, protected areas, and agricultural regions designated as important to determine the proximity of these opportunities to essential landscapes that may have otherwise be selected for energy siting and development. Next, we (4) analyze the spatial density of contaminated sites within 10 km of the most populated CV cities to elucidate relationships between attributes (number and size) of nearby contaminated sites potentially favorable for solar energy generation and urban development centers because urban density is an explicative factor determining electricity consumption for cities.[64] Lastly, we (5) test the degree to which current and projected (2025) electricity needs for the state of California can be met across all four potential land sparing opportunities.

METHODS

Theoretical and Technical Solar Energy Potential for PV and CSP Technologies. The theoretical, or capacity-based, solar energy potential is the radiation incident on Earth's surfaces that can be utilized for energy production, including solar energy.[65] We used two satellite-based radiation models developed by the National Renewable Energy Laboratory (NREL) and Perez et al.[66] to estimate the theoretical solar energy potential of PV and CSP technologies operating at their full, nominal capacity over 0.1° surface cells (∼10 km in size).

Photovoltaic technologies use both direct and indirect radiation, while CSP uses only direct-beam radiation. Therefore, the radiation model we used for CSP capacity-based energy estimates is representative of direct normal irradiance (DNI) only, whereas the PV model incorporates both DNI and diffuse irradiance. Areas with DNI values of less than 6 kWh m^{-2} day^{-1} were not considered economically adequate for CSP deployment and therefore excluded from solar potential estimates (Figure S1).

To evaluate the technical, or generation-based, solar energy potential within identified areas for land-sparing PV development, we multiplied the theoretical potential by a capacity

DOI: 10.1021/acs.est.7b05110
Environ. Sci. Technol. 2017, 51, 14472−14482

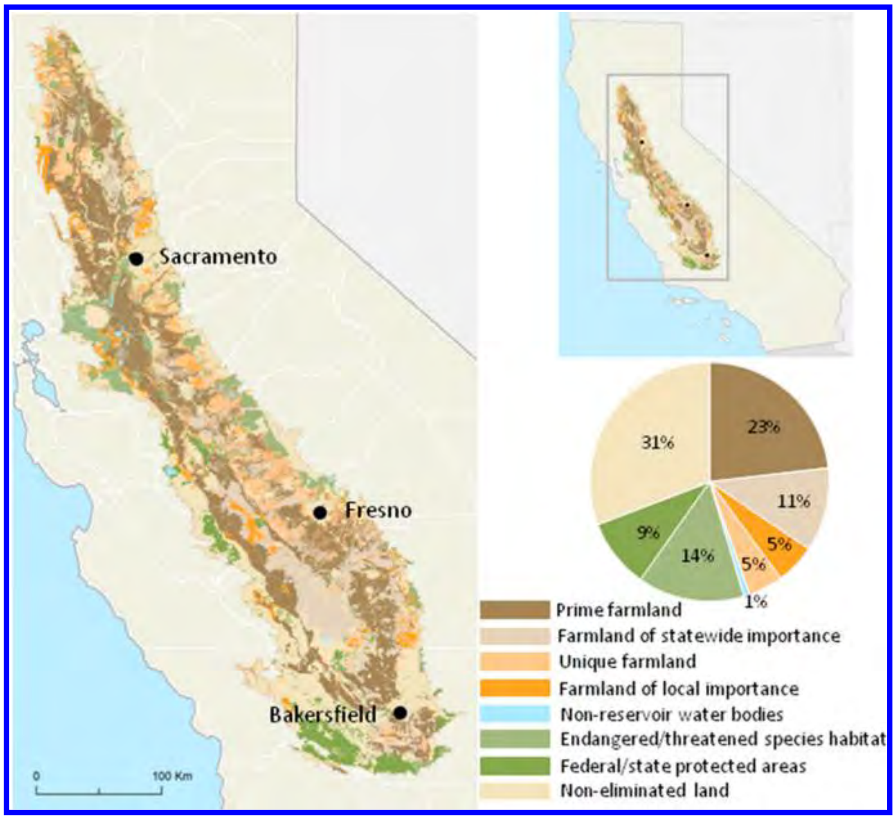

Figure 2. Map of California showing land-cover types eliminated when identifying solar energy potential over salt-affected soil. The pie graph depicts the relative proportion of area that each land cover type makes up within the Central Valley, which is not visible in the map due to overlap (e.g., areas identified as both endangered species habitat and state-protected). Land-cover types include: important farmlands (prime, unique, and of state-wide or local importance), nonreservoir bodies of water, endangered and threatened species habitat, federally and state-protected land, and non-eliminated land that was further evaluated for solar energy potential. The map was made using ESRI ArcGIS Desktop (version 10.4) software.

factor. The capacity factor values are derived from a satellite-based, spatially explicit capacity factor model[67] that has identical cells as the radiation models described above. The PV capacity factor model comprises estimates for three primary technology subtypes including fixed mount, south facing with a 25° tilt (TILT25); one-axis tracking, rotating east−west with a ± 45° maximum tracking angle (AX1FLAT); and two-axis tracking, rotating east−west and north−south of the sun across the horizon (AX2). For CSP generation-based calculations, we incorporated a five DNI class value scheme resembling estimates for a trough system.[68] Full details are provided in the Supplementary Methods.

Next, we calculated solar energy potential for both small and large-scale solar energy projects, where a minimum parcel size of 28 490 m^2 and 29 500 m^2 were required for PV and CSP facilities, respectively, producing 1 MW or more. These values are based on the average USSE land-use efficiency of 35.1 and 33.9 W m^{-2} for PV and CSP, respectively.[69] All CSP installations are utility-scale, and therefore, only these data are reported.

Solar Energy Potential of Land Sparing Opportunities in the Central Valley. We delineated the CV (58 815 km^2) based on the Great Central Valley Region[70] (Figure 1), composed of the geographic subdivisions of the Sacramento Valley, San Joaquin Valley, and all Outer South Coast Ranges encompassed within the San Joaquin Valley polygon. We overlaid the PV and CSP radiation models with the four land sparing land-cover types within the CV and calculated total area (km^2) and solar energy potentials (TWh $year^{-1}$). Across the salt-affected land solar energy TESs, we eliminated lands protected at the federal and state levels and threatened and endangered species habitats (Figure 2). Furthermore, all water bodies (e.g., wetlands and rivers), occurring in salt affected areas, with the exception of reservoirs, were removed as they may function as essential habitats for birds and other wildlife. Salt-affected soils within farmlands identified as primary, unique, or of state-wide or local importance[71] were also not included in the final estimates for solar energy potential. See the Supplementary Methods for explicit details on data and analysis for each land-cover type.

Spatial Relationships between Synergies and across Land-Cover Types. To ensure that energy potentials were not double-counted (e.g., salt-affected lands within the built environment), we calculated the spatial overlap across three solar energy TESs. Specifically, we observed overlap of land sparing potential among the built environment, salt-affected regions, and reservoirs. We did not include Environmental Protection Agency (EPA) contaminated sites because such data is not absolutely spatially explicit, but instead, each site is modeled circularly, in known total area, outward from a centroid based on known latitude and longitude coordinates, which may not represent each site's actual boundaries. Overlap between contaminated sites and land classified as salt-affected may be the most unlikely as most actions at these sites focus on preventing human contact.[41] Nonetheless, we did count 17 (189.5 km^2), 3 (2.5 km^2), and 740 (332.8 km^2) contaminated sites that may potentially overlap with salt-affected land, reservoirs, and the built environment, respectively, but we did

DOI: 10.1021/acs.est.7b05110
Environ. Sci. Technol. 2017, 51, 14472−14482

Table 1. Contaminated Site Attributes across the Ten Most-Populated Cities Within the Central Valley, CA

city	city population	city area (km^2)	contaminated sites within city	contaminated sites within 10 km of city	contaminated site area within 10 km (km^2)
Fresno	494 665	112	38	58	21
Sacramento	466 488	98	83	140	47
Bakersfield	347 483	142	10	32	8
Stockton	291 707	62	53	95	35
Modesto	201 165	37	19	55	28
Elk Grove	153 015	42	27	71	52
Visalia	124 442	36	36	46	9
Concord	122 067	31	9	60	107
Roseville	118 788	5	8	60	75
Fairfield	105 321	37	10	26	34

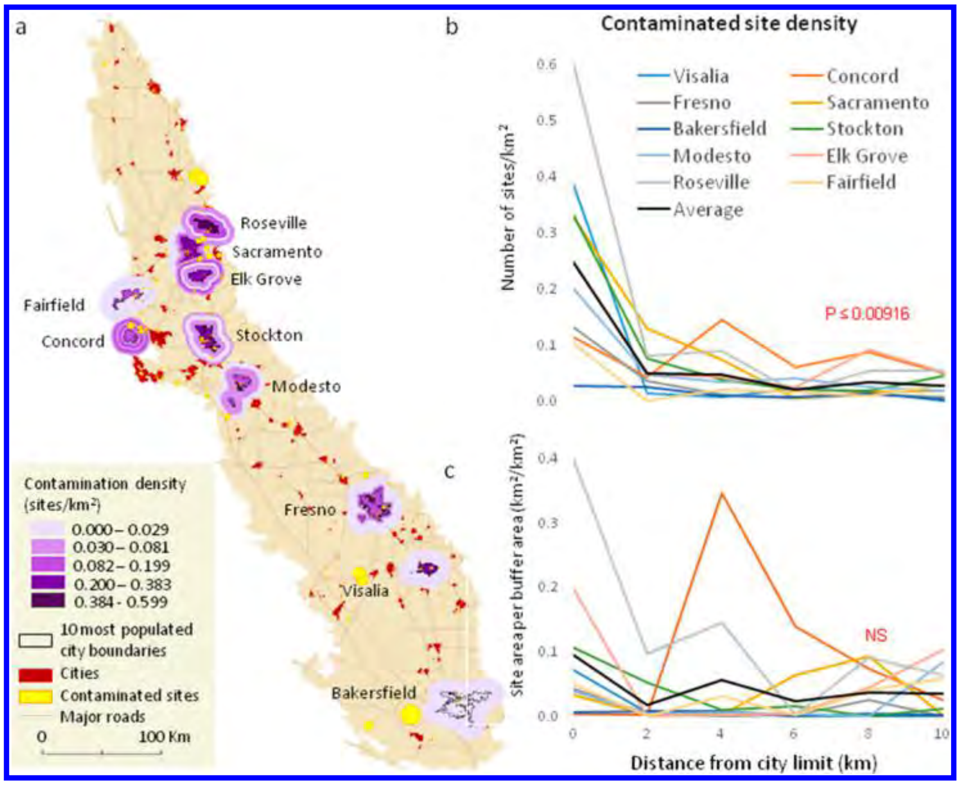

Figure 3. (a) Density of contaminated sites (circular points representing their total area but not shape; number of sites per square kilometer) within the Central Valley's (beige polygon) 10 most-populated cities: (1) within city limits (black line) and (2) across 0−2, 2−4, 4−6, 6−8, and 8−10 km buffers beyond city borders (purple buffers). Graphs show (b) the density of contaminated sites (sites per square kilometer) and (c) the total area of sites as a function of distance from city limits of the 10 most-populated cities in California's Central Valley. Land within each city boundary has a significantly greater number of contaminated sites based on total count (posthoc Tukey test, $P \leq 0.00916$) than buffer classes beyond the city perimeter (number of sites per square kilometer). No significant relationship exists between contamination site area and distance from urban cores. The map was made using ESRI ArcGIS Desktop (version 10.4) software.

not account for this overlap in the final values. We also enumerated spatial relationships between synergistic sites and other land-cover types throughout our analysis to determine the proximity of these opportunities to essential landscapes that may have otherwise been selected for energy siting and development.

Spatial Density and Proximity of Contaminated Lands to Human Populations. To elucidate relationships between attributes (number and size) of nearby contaminated sites potentially favorable for solar energy generation and urban development centers, we first identified the 10 most-populated cities within the Central Valley. We added 5 buffer distances around the perimeter of each city at 2 km increments up to 10 km (i.e., 2, 4, 6, 8, and 10 km). Within cities and each of these buffered rings (e.g., area between 4 and 6 km beyond city limits), we calculated the area and divided the number and area of contaminated sites that fall within each buffer by its associated area (site km^{-2} and site area [km^2] km^{-2}). We included any sites located outside of the CV within 10 km of the city analyzed. Contaminated sites that were in a 10 km radius of more than one of the 10 highly populated city were included in each density analysis. We used generalized linear models (GLMs) to test the effects of distance class on contaminated site metrics (i.e, count and area) and to observe if sites are generally located near, further away, or have no association with urban development centers, which serve as a proxy for electricity demand. Contaminated sites that were within a 10 km radius of multiple cities were observed

DOI: 10.1021/acs.est.7b05110
Environ. Sci. Technol. 2017, 51, 14472−14482

Table 2. Number of Times over PV and CSP Solar Energy Technologies Can Meet California'S Projected Electricity Consumption Needs for 2025 (321 TWh) Based on Land-Sparing Opportunities within the Central Valley, CA: (1) Developed, (2) Salt-Affect Soil, (3) Reservoirs, and (4) Contaminated Sites[a]

		PV				CSP	
		distributed and USSE		USSE only		USSE	
land-cover type[b]		capacity-based (times over)	generation-based (times over)	capacity-based (times over)	generation-based (times over)	capacity-based (times over)	generation-based (times over)
Central Valley		378.6	68.1–83.4	378.6	68.1	398.2	129.7
DNI ≥ 6 kWh m^{-2} day^{-1}		–	–	–	–	135.4	46.9
developed	high intensity	2.8	0.5–0.60	1.5	0.3	–	–
	medium intensity	10.8	1.9–2.35	7.5	1.3–1.6	–	–
	low intensity	9.3	1.7–2.02	1.6	0.3–0.4	0.2	0.1
	open space	19.2	3.5–4.2	6.2	1.1–1.4	1.9	0.7
salt-affected soil	EC ≥ 4 and ≤8	0.6	0.1	0.6	0.1	0.2	0.1
	EC > 8 and ≤16	0.8	0.1–0.2	0.8	0.1–0.2	0.3	0.1
	EC > 16	0.1	0.0	0.1	0.0	0.0	0.0
	SAR ≥ 13	0.2	0.0	0.2	0.0	0.0	0.0
	overlap (EC ≥ 4 and SAR ≥ 13)	3.9	0.7–0.9	3.9	0.7–0.9	1.4	0.4
reservoirs		0.7	0.1–0.2	0.6	0.1	–	–
contaminated		7.1	1.3–1.6	7.0	1.3–1.6	3.0	1.0
total		55.4	9.9–12.1	30.1	5.4–6.6	7.0	2.4
overlapping areas		1.3	0.2–0.3	0.6	0.1	0.1	0.0
total (accounting for overlapping areas)		54.1	9.7–11.8	29.5	5.3–6.5	6.9	2.4

[a]Capacity-based potential is representative of the full energy potential offered from the sun, whereas the generation-based potential estimates the energy potential given current technology capabilities including three PV system types (tilt, one-axis tracking, and two-axis tracking panels) and a CSP trough technology. [b]Total energy potentials account for overlaps in land-cover types to avoid double-counting.

separately and therefore accounted for more than once. See the Supplementary Methods for further details.

RESULTS AND DISCUSSION

We found that 8415 km^2 (equivalent to over 1.5 million American football fields) and 979 km^2 (approximately 183 000 American football fields) of non-conventional surfaces may serve as land-sparing recipient environments for PV and CSP solar energy development, respectively, within the great CV and in places that do not conflict with important farmlands and protected areas for conservation (Figure 1 and Tables 1 and Supplementary Table 1). This could supply a generation-based solar energy potential of up to 4287 TWh year^{-1} for PV and 762 TWh year^{-1} for CSP, which represents 2.8 (CSP) – 14.4% (PV) of the CV area. We accounted for 203 km^2 of overlap across the built-environment, reservoirs, and salt-affected areas, the latter after eliminating land classified as protected areas (federal and state), critical and threatened habitats, and important farmlands from salt-affected soils.

In total, the CV encompasses 58 649 km^2 of CA, about 15% of the total land area in the state, and has a theoretical potential of 121 543 and 127 825 TWh annually for PV and CSP, respectively (Table S1). Considering areas with solar radiation high enough to economically sustain a CSP solar energy facility (locations with a DNI of 6 kWh m^{-2} year^{-1}), less than one-third (~19 000 km^2) of the CV is suitable for CSP deployment, and a capacity-based potential of about 44 000 TWh year^{-1}.

Among the potential solar energy TESs we studied, the built environment offers the largest land sparing potential in area with the highest solar energy potential for PV systems (Figure 1a), representing between 57% (USSE only) and 76% (small-scale to USSE) of the total energy potential for PV. If only USSE PV systems are considered for development, roughly half of the total built environment is suitable, a constraint owing to areas not meeting minimum parcel requirements for a one MW installation (28 490 m^2 or greater). Specifically, installing PV systems across the built environment could provide a generation-based potential of 2413 TWh year^{-1} utilizing fixed-tilt modules and up to 3336 TWh year^{-1} for dual-axis modules (Table S2). Using CSP technology, both the low-intensity developed and the open spaces within the built environment could yield 242 TWh year^{-1} of generation-based solar energy potential (Table S1). For CSP, the built environment represents 30% of all energy opportunity for the land-sparing solar energy TESs we studied.

Land with salt-affected soils, another potential land sparing solar energy TES, comprises 850 km^2 of the CV, excluding areas identified as important for agriculture and conservation (Figure 2). This remaining salt-affected land makes up 1.5% of the CV region. Generally, regions with high concentrations of salt also have unsuitable levels of sodium. Indeed, we found that 70% of sodic and saline soils overlap; occurring in the same place (Table S2). Geographically, most salt-affected land sparing opportunities suitable for solar energy development are within the interior region of the CV, away from the built environment (Figure 1c).

We found that 2% (1098 km^2) of the CV is composed of contaminated lands with a generation-based potential of 407 and 335 TWh year^{-1} for PV and CSP, respectively. A total of 60% of these sites are clustered within and near (<10 km) the 10 most-populated cities, a buffer area composed of 21% of the CV (inclusive of buffer areas of cities extending beyond the CV border; Figure 3a and Table 1). We found that across the top 10 most-populated cities, population was significantly positively related to the number of contamination sites (GLM, t value of 2.293, P = 0.025916). We also found that land within each city

DOI: 10.1021/acs.est.7b05110
Environ. Sci. Technol. 2017, 51, 14472–14482

boundary has a significantly greater number of contaminated sites based on total count (post-hoc Tukey test, $P \leq 0.00916$; Figures 3b and S2) than buffer classes beyond the city perimeter (number of sites per square kilometer; Figure 3b). We found no statistical relationship between contamination site area and distance from urban cores (Figure 3c). Note that in addition to the 953 contaminated sites quantified for solar energy potential, 51 more sites are included in the density analysis that reside outside of the CV boundary but are within 10 km of cities and 46 of the contaminated sites (Table 1) are accounted for multiple times because they are within the 10 km radius of multiple cities. Lastly, contaminated lands are particularly attractive for USSE projects, and indeed, 412 and 411 of the 953 contaminated sites from the EPA data set pass the minimum area requirement for supporting utility-scale PV and CSP technologies, respectively (Figure 3). Although our emphasis here was relationships between contaminated sites and urban development cores, more-robust analyses exploring spatial relationships between contaminated sites and population at the regional scale may be useful.

Reservoirs comprise 100 km^2 of available surface area for solar energy, just 0.2% of the total land area in the CV. The integration of fixed-tilt PV panels across all reservoir surface area would provide a generation-based energy potential of 39 TWh $year^{-1}$ (Table S1). There are roughly 4300 reservoirs within the CV, 2427 (56%) and 986 (23%) of which are classified as water storage and reservoirs, respectively (Figure S3). These water body types are the greatest targets for floatovoltaic development, and together, they make up roughly 66% of the total surface area of all reservoirs in the CV. While 66% of reservoirs identified in the CV are highest priority, the remaining 38% are treatment, disposal, and evaporator facilities, aquaculture, and unspecified reservoirs (Figure S3). In CA, farmers and water pump stations consume 19 TWh of electricity annually;[72] based on estimated energy potential for floatovoltaics, reservoirs provide enough surface area to supply 2 times the electricity needs of farmers or water pump stations for CA (19 TWh).[72]

California's projected annual electricity consumption needs for 2025, based on moderate assumptions, is 321 TWh.[73] The land-sparing solar energy TESs we explore in this study could meet CA's projected 2025 needs for electricity consumption between 10−13 times over with PV technologies and over two times over with CSP technologies (Table 2). In fact, each land-sparing TES individually can be used to meet the state's energy needs with the exception of reservoirs, which would provide enough surface area to produce electricity to meet 10−20% of CA's 2025 demands. However, reservoirs do offer enough surface area and potential to meet electricity needs within California's agriculture sector (i.e., 19 TWh annually).[72] CSP systems are confined to limited areas within the CV and therefore offer relatively less energy potential than PV; yet still, contaminated lands alone offer adequate space for CSP technologies to meet projected electricity needs for 2025.

Our study found contaminated sites are clustered within or near highly populated cities, many with populations that are projected to rapidly expand owing to urban growth. Thus, contaminated sites may serve as increasingly desirable recipient environments for solar energy infrastructure within the CV of California and agricultural landscapes elsewhere. The mission of the Environmental Protection Agency's (EPA) RE-Powering initiative is to increase awareness of these contaminated sites by offering tools, guidance, and technical assistance to a diverse community of stakeholders. Already, this program has facilitated development from 8 renewable energy projects in 2006 to nearly 200 today.[44] Across the United States alone, there are over 80 000 contaminated sites across 175 000 km^2 of land identified as having renewable energy potential, emphasizing the opportunity to repurpose under-utilized space. Given the globally widespread policy-based adoption of managing hazards in place, allowing for the less than complete remediation of environmental hazards on contaminated sites; the benefits of this TES must be weighed against risks assessed from indefinite oversight and monitoring.[41]

There are few studies or cost−benefit analyses on solar energy over functional water bodies that empirically and quantitatively assess the potential for synergistic outcomes related to water (e.g., water quality), energy, and land. Farmers frequently build water reservoirs to cope with limits on water allotment during drought periods,[74] offering opportunities for dual-use space for solar panels. Although floatovolaics are increasing in popularity, particularly in Asia, where the largest floating solar installation exists,[75] more-comprehensive environmental impact assessments are needed to quantify beneficial outcomes (e.g., reductions in evaporative loss) and address risks. One concern is that avian species may perceive PV modules as water, known as the "lake effect," leading to unintended collisions and possibly injury or mortality.

In 2015, installed capacity of solar energy technologies globally reached 220 GW driven by relatively high average annual growth rates for PV (45.5%, 1990−2015) and CSP (11.4%) compared with other renewable energy systems.[76,77] At these rates, trade-offs between land for energy generation and food production in an era of looming land scarcity may be high[9] when developed without consideration of impacts to land, including food and natural systems. For example, in the United States alone, an area greater than the state of Texas is projected to be impacted by energy development and sprawl, making energy the greatest driver of LULCC at a pace double the historic rate of residential and agricultural development by 2040.[28] California aims to derive half of its electricity generation (160 TWh) from renewable energy sources by 2030, and we show that the CV region can supply 100% of electricity needs from solar energy without compromising critical farmlands and protected habitats.

The extent to which agricultural landscapes can sustain increasing demand for agricultural products and transition to becoming a major solution to global change type threats instead of contributing to them depends on several factors; however, the manner in which land, energy, and water resources are managed within such landscapes is arguably the decisive factor.[4,78] Our study reveals that the great CV of California could accommodate solar energy development on nonconventional surfaces in ways that may preclude loss of farmland and nearby natural habitats that also support agricultural activities by enhancing pollinator services (e.g., wild bees) and crop yields.[79,80] Given the diffuse nature of solar energy, advances in battery storage would likely only enhance the economic and environmental appeal of the four solar energy TES we evaluated.[81,82] The realization of this potential may also confer other techno-ecological synergistic outcomes (as characterized in Figure 1), and additional research could be conducted to improve the certainty and accuracy of these potential benefits. For example, the degree to which realization of solar energy potential in agricultural landscapes on nonconventional surfaces contributes to food system resilience[83] by alleviating competi-

DOI: 10.1021/acs.est.7b05110
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tion of valuable land among farmers, raising property values, generating clean energy for local communities, enhancing air quality, and providing new job opportunities[14,62] remains largely unexplored.

Other factors impacting the sustainability of agricultural landscapes include the level of funding to support research and development, collaboration across public and private sectors to advance technology and innovation, and policies that bolster decisions and action leading to appropriate renewable energy siting. Research efforts have increasingly focused on identifying where and how renewable energy systems can be sustainably integrated into complex landscapes with environmentally vulnerable ecosystems,[21,22,84−86] but less emphasis has been on decisions with agricultural landscapes[19,78,84,85] despite its importance to food security and nutrition. In the US, the National Science Foundation is prioritizing the understanding of food, energy, and water interactions, identifying it as the most pressing problem of the millennium, but land has remained underemphasized in these programs.[87] Policies that result in cash payments to growers and solar energy developers for land sparing energy development could facilitate, indirectly, the conservation of important farmlands and natural areas. Federal policy could provide the financial support to state and local governments to protect natural and agriculturally critical areas, and decisions can be tailored at these administrative levels to accommodate the land use and water rights unique to the region.

California's Great Central Valley is a vulnerable yet indispensable region for food production globally. Our analysis reveals model options for sustainable solar energy development via use of nonconventional surfaces, i.e., the built environment, salt-affected land, contaminated land, and water reservoirs, as floatovoltaics. These land sparing solar energy development pathways may be relevant to other agricultural landscapes threatened by trade-offs associated with renewable energy development and sprawl.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.7b05110.

> Detailed information about methods and data used for analysis in this study. Figures showing the effect of distance from the 10 most-populated cities, water reservoirs in the Central Valley, theoretical solar radiation potential, and maps of land-sparing solar energy. Tables showing utility-scale solar energy potential and photovoltaic energy potential.(PDF)

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We thank Max Wei, Michelle Murphy-Mariscal, Steve Campbell, Steven Grodsky, and California Audubon for comments that greatly improved this manuscript. Funding was provided by the Center for Conservation Biology (University of California at Riverside); the Schneider Climate and Energy Stewardship (Stanford University and the Audubon California), Agricultural Experiment Station Hatch projects CA-R-A-6689-H and CA-D-LAW-2352-H; the California Energy Commission; and the Department of Land, Air, and Water Resources at University of California Davis.

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DOI: 10.1021/acs.est.7b05110
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Hall, Harold <harold.hall@bia.gov>

[EXTERNAL] Fw: Petition to appose Terra-Gen

1 message

Angie Adkins <evangelineadkins@yahoo.com> Thu, Dec 20, 2018 at 8:01 AM
To: "harold.hall@bia.gov" <harold.hall@bia.gov>

Please accept attached petition.

My daughter is extremely sensitive to wind turbine noise.

We were very worried when the ones North of Highway 8 went in and she hasn't been affected. We are afraid that more in the area will affect her health.

I would be happy to speak to you on this issue.

Thank you for your time.

Sincerely,

Evangeline Adkins
619-507-5511

Petition.pdf
53K

Hall, Harold <harold.hall@bia.gov>

[EXTERNAL] Campo Wind Scoping Comments

1 message

Aaron Peterson <agpblvd@yahoo.com> Fri, Dec 21, 2018 at 12:24 PM
To: "harold.hall@bia.gov" <harold.hall@bia.gov>, "bronwyn.brown@sdcounty.ca.gov" <bronwyn.brown@sdcounty.ca.gov>, Donna Tisdale <tisdale.donna@gmail.com>

Hello,

I support and endorse the comments submitted by the Boulevard Planning Group dated December 20, 2018.

Aaron Peterson

Hall, Harold <harold.hall@bia.gov>

[EXTERNAL] Campo Wind EIS scoping comments - BAD 2

1 message

Donna Tisdale <tisdale.donna@gmail.com> Fri, Dec 21, 2018 at 12:20 PM
To: harold.hall@bia.gov, "Brown, Bronwyn" <Bronwyn.Brown@sdcounty.ca.gov>

Mr. Hall and Ms. Brown,

Please confirm receipt of the attached reports on noise and electrical pollution testing to be included as part of our formal comments opposing Terra-Gen's Campo Wind and connected Torrey Wind projects.

These reports are being submitted on behalf of Backcountry Against Dumps and Donna Tisdale as an individual and are in addition to previous and/or pending comments:

1. Wilson & Ihrig: "KUMEYAAY AND OCOTILLO WIND TURBINE FACILITIES NOISE MEASUREMENTS" dated 2-28-14
2. Environmental Assay,Inc: "Assessment of Power Quality and Electromagnetic Field (EMF) Exposure at Campo and Manzanita Reservation Residences near the Kumeyaay Wind Turbines, And Ocotillo-Area Residences near the Ocotillo Wind Energy Facility Wind Turbine Electric Generator Installation": dated 2-13
3. Environmental Assay Inc: Appendix A
4. Environmental Assay Inc: Appendix B-D

Here is a list of the Wilson Ihrig loca on distance and highest level frequency recorded:

D. Ellio 2000 . 55 dB 1.56 Hz; G. Thompson 2940 ft 58 dB 1.66 H; R. Ellio 4300 ft 55 dB 0.68 Hz; Live Oak Springs Cabin#2 5890 ft 48 dB 2.54 Hz; Oppenheimer 1.6 miles 45 dB 0.88 Hz; Morgan 1.7 miles 56 dB 1.56 Hz; D. Bonfiglio 2.9 miles 43 dB 1.07 Hz; Tisdale 5.6 miles 43 dB 0.68 Hz

Environmental Assay Inc documented the following at impacted homes, some with power on and /or off: electrical noise, progressive and wide-band electromagnec interference (EMI), grounding current, frequency harmonics, magnec fields (Appendix A). The author's quote from page 5 of the main report states that: "*All residences displayed electrical characteris cs within their electrical systems that are foreign to their electrical devices and related consump on characteris cs. That is, these characteris cs were detectable even with no power in use within the residences inves gated (main breaker open/off). By virtue of the Electric field availability from installed wiring, all of these uncommon electrical characteris cs (whether with power on or off) became a component of chronic personal exposure)*".

Regards

Donna Tisdale, President

Backcountry Against Dumps

PO Box 1275, Boulevard,CA 91905

619-766-4170

4 attachments

Wilson & Ihrig WT report 2-28-14 final.pdf
4986K

Manzanita WT Report - Body 2-24-13 FINAL.pdf
698K

Manzanita WT Report - Appendix A 2-14-13 FINAL.pdf
1088K

Manzanita WT Report Appendices B,C,D 2-14-13 FINAL.pdf
366K

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Javier Beltran DATE: 12-10-2018

ADDRESS: PO Box 2604 Alpine CA. 91903

COMMENTS: See Attached Reasons Against.

PACIFIC REGIONAL OFFICE
BUREAU OF INDIAN AFFAIRS
2018 DEC 17 PM 3:05

Reg Dir ✓
Dep RD Trust ✓
Dep RD IS
Route N/R
Response Required
Due Date
Memo Ltr
Fax

Reasons Against Permitting Industrial Windmill Businesses in Campo.

-Visually ugly and completely out of place in pristine mountain environment. Aesthetically disastrous.

-Will diminish quality of life to be surrounded by gigantic spinning structures.

-Numerous birds will be killed.

-Alleged minimal environmental "benefit," is offset by the production of materials necessary to build, transport, operate, decommission and eventually dismantle. The San Francisco area dismantled over 800 gigantic wind turbines just a few years ago due to excessive bird kill.

-Flashing red lights connecting the tops of windmills will be annoying and end watching the night sky, stars and moon.

-Placing numerous electrical creating structures in a high fire zone area should be outlawed, as electrical sparks have caused catastrophic fires, killing people, animals and plants in this area and other parts of Cal.

-Sun flicker and shadows through the blades would be extremely annoying and a potential health hazard.

-Tourism to the Golden Acorn Casino area will decline when it becomes known as a dumping ground for such projects. The tribal areas would be much more profitable by expanding casinos, hotels, golf courses, or architecturally pleasing shopping outlets, similar to Viejas.

-Sellout landowners/ builders make a temporary profit from subsidies paid by your tax money and higher electric rates, while neighbors and the community have a permanent loss of property value and quality of life.

Hall, Harold <harold.hall@bia.gov>

[EXTERNAL] Campo Wind Scoping Coments

1 message

Jeffrey Morrison <eastcountyproperty@yahoo.com> Wed, Dec 19, 2018 at 12:20 PM
Reply-To: Jeffrey Morrison <eastcountyproperty@yahoo.com>
To: harold.hall@bia.gov
Cc: Donna Tisdale <tisdale.donna@gmail.com>, "calpolyslomom@gmail.com" <calpolyslomom@gmail.com>, Bronwyn Brown <bronwyn.brown@sdcounty.ca.gov>, Carrie Sahagun <csahagun@blm.gov>, "dianne.jacob@sdcounty.ca.gov" <dianne.jacob@sdcounty.ca.gov>

Dear Mr. Hall, Hon Dianne Jacob and Ms Brown,

I am very concerned with the Campo Wind Project. The Tule Wind Project has already proven to affect my family's health and well being. This project places even larger and taller windmills closer to my home. I purchased this home in 1997 a. er having lived in this area since 1967. My wife and I are experiencing problems with the current project that was put into opera□ on some□me around November 2017. I have experienced increasing health issues with the noise frequency and electromagne□c energy that they produce. My wife has issues with ver□go that are exponen□ally increased by these windmill's rota□on and shadows.

We have lost sleep and suffer anxiety with these windmills. For the first □me in 50 years, I have had to close the windows at night so I don't hear the constant whooshing and humming as bad from these awful inven□ons. Even with the windows closed, we can hear these things all night long as well as see the red lights flashing in our mirrors.

I have seen these things also catch on fire two miles from my home. They are dangerous !!!

These things affect so many things that I am surprised they have not been outlawed. I can believe my family's health and welfare, as well as the welfare of fellow ci□zens and environment, are placed in jeopardy for some greedy companies. I cant believe the government is suppor□ng these projects, it is destroying the environment and well documented that it affects the well being of people.

I am seriously concerned about public health & safety impacts as well as decreasing property values. One day someone will care more for the people and the rest of the world rather than how fat their wallet is.

I strongly oppose this project and will con□nue to fight as hard as necessary to stop this lack of care for people and property.

Jeff Morrison
P.O. Box 1116

Boulevard, California 91905
619-766-4408

Hall, Harold <harold.hall@bia.gov>

[EXTERNAL] EIS Scoping Comments, Campo Wind Project, San Diego County, California

1 message

Katherine Edgerley <kedgerle@uw.edu>
To: harold.hall@bia.gov

Mon, Dec 3, 2018 at 4:45 PM

Dear Mr. Dan (Harold) Hall,

The following is a public comment regarding the Notice of Intent To Prepare an Environmental Impact Statement (EIS) for the Proposed Campo Wind Energy Project, San Diego, California. I am writing to provide EIS Scoping Comments in support of the Campo Wind Project in San Diego County, California (Agency/Docket Number: 190A2100DD/A0A501010. 999900253G). This action is providing notice of intent to evaluate the potential environmental impacts of the proposed Campo Wind Project. This project is located on the Campo Indian Reservation in San Diego County and would generate up to 252 MW of power from up to 60 turbines on 2,200 acres.

I am in support of the ultimate implementation of this project as it not only furthers California's goal of 100% renewable electricity generation by 2045 (SB 100), but it also provides the potential of enhanced economic development for the Campo Kumeyaay Nation within the Campo Indian Reservation.

Wind energy production already exists within in the Reservation, but with the defeat of the Shu'luuk Wind Project in June 2013, I believe the Bureau of Indian Affairs (BIA) has an opportunity to provide an EIS that will provide adequate information to hopefully assuage the opposition to the new project. I believe that a process of stakeholder engagement to produce a comprehensive EIS will allow a new wind energy project to be implemented in the Reservation.

In 2013, opposition resulted from concerns regarding the risk of fire, perceived health impacts, and quality of life (Clarke, 2016). Therefore, I suggest particular emphasis to be placed on the evaluation of impacts regarding:

- Air quality (vegetation management could be proposed as a mitigation measure to decrease the likelihood of devastating fires in the area),
- Aesthetics,
- Noise (ensure that siting of the project is far enough away from homes and businesses such that noise impacts are reduced),
- Historic and cultural sites, and
- Economic impacts.

Since this project would be implemented within the Campo Indian Reservation, special attention must be paid to any potential impacts to historic and cultural sites and resources. There is the potential of members of the Campo Kumeyaay to view this project as more white people showing up with ways to "improve" the member's lives. This remnant of the harms of colonization should be recognized. By engaging with tribe members, ensuring that the project will not be in harmful (to lives, cultural and environmental resources, etc.) places, and providing opportunities for tribe members to directly benefit from this project are ways to provide ownership to the Campo Kumeyaay Nation.

For the Campo Kumeyaay Nation to fully realize the economic development potential of this project, simply leasing its land to a private company does not seem optimal. By only leasing its land, the Campo Kumeyaay Nation loses out on any profits from the project. Connolly presents multiple options for shared ownership of such renewable energy projects and other tax incentives the Campo Kumeyaay Nation can leverage to benefit its people and diversify the Nation's economic development strategy (Connolly, 2008).

Overall, I believe this project can be successful if the BIA and Campo Kumeyaay Nation work together and fully engage with the stakeholder-ing process. I implore the lead and cooperating agencies to meet interested parties where they are. By taking the project to the people who may be for or against the project, you will be sure to produce the most comprehensive document that will hopefully resolve any worries or issues individuals may have with this project. The Shu'luuk Wind Project lost in a vote of 44-34 in June 2013, so support of expanded wind energy within the Reservation exists. Also, the failure in 2013 allows clear direction of where to enhanced this project's EIS to ensure acceptance and eventual passage by the Campo Kumeyaay Nation's General Council.

Sincerely,

Katherine Edgerley

MPA Candidate at the University of Washington

References

Clarke, C. (2016, February 14). Wind Project on Tribal Land Dies Quietly. Retrieved from https://www.kcet.org/redefine/wind-project-on-tribal-land-dies-quietly

Connolly, M. L. (2008). Commercial Scale Wind Industry on the Campo Indian Reservation. *Natural Resources & Environment*, *23*(1), 25-28.

By 12/21/18 Send to: Ms. Amy Dutschke, Regional Director, Bureau of Indian Affairs, Pacific Regional Office, 2800 Cottage Way Sacramento, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Lorrie Ostrander **DATE:** Dec. 13, 2018

ADDRESS: 43577 OLD Hwy 80 Jacumba, CA.

COMMENTS:

please Read attached comments

Lorrie Ostrander

Reg Dir
Dep RD Trust
Dep RD IS
Route N/R
Response Required
Due Date
Memo Ltr
Fax

My husband and I have been living in the Back Country (also Known as Mountain Empire region) since 1992 (26yRs). Over the years there has been a huge change - air quality, our Wells, habitat and health issues. Air: in 1992 the skies were clear and free of dust. Today (2018) as one drives West to East you can see dirt in the sky, plus you can smell it. Wells: due to so many projects that are taking place, our Wells are dropping. Habitat: Golden Eagles once flew in our area, but when the Turbine projects (and other projects) began on the ~~Campo~~ LaPosta Reservation, Eagels are no more, the Deer, Mountain Sheep, Puma, Badger, that use to live on the North of Hwy 8 have been forced out of their natural habitate, their food source has been depleated. The Chapparell has been destroyed. Health: there is a rise in Cancer, allergies, migraines ever since the first Turbine project was place on the Reservation and now Campo Reservation wants to destroy 2200 acres for more turbines. The life of our firefighters are also put in harms way, on the ground and in the air.

"POINT of Need" is where they (turbines) should be located!

There are 2 comments that echo in my head each time there are meetings for a new project: "CRush them! FORce them all out and make the area energy land". Two Governors - ARnold S. and BRown spoke these words.

The other comment that was spoken a few years ago was from a past Chair person ~~on the~~ at a Campo Tribal meeting that was an open meeting to the Public.

Her words were: "I'll do whatever it takes to feed my family and my people".

Maintinance on the existing Turbines are always taking place; we can see Oil leaking from the blades. Because of these turbines we have more and more Wild life in our back yard - Puma, Bobcats, Badger, etc. Coyotes are hairless due to the stress of blasting, drillings, traffic of trucks, lack of water and their food source. So, I guess the Campo Tribal Chairperson succeeded in her comment. The Tribe forgets one thing - "We are the protecters of the Air we breathe, the Water of life, the Land that provides us food, shelter, etc. and all of our brothers of our Creators Creatures".

Green energy it is NOT, it is GReed energy.

Final: When the animals are gone, water and air has depleted so Will MAN.

NO to further destrction of the Back Country - "POINT of Need".

Lorrie Ostrander
Jacumba, CA.

Lorrie A. Ostrander
43577 Old Highway 80
Jacumba, CA 91934

Hall, Harold <harold.hall@bia.gov>

[EXTERNAL] Campo Wind Scoping comments

1 message

Marie & Scott Morgan <smorgy@hughes.net> Fri, Dec 21, 2018 at 11:04 AM
To: harold hall <harold.hall@bia.gov>

Dear Mr. Hall,

We would like to voice our concerns regarding the proposed Terra-Gen's Campo Wind and Torrey Wind projects in the Boulevard area. We are residents of Boulevard and live on the north end of Ribbonwood Rd. Our home is currently impacted on the East and North by the Tule Wind project and on the West by the existing Kumeyaay wind turbines. We have experienced the significant noise produced by these turbines as well as a negative impact on our scenic landscape and property value. The proposed Terra-Gen Campo & Torrey wind projects will bring wind turbines even closer to our home as well as homes of neighbors on and off of reservation lands. These turbines are considerably larger than the existing projects and will subject residents to even more adverse impacts from increased noise, potential health issues, increased fire risk and scenic landscape degradation which will further negatively impact property values.

We are retired seniors on fixed income (as are many of our neighbors) and if it becomes necessary to leave our home due to the impacts associated with these wind turbine projects our property will be potentially unsalable, making it impossible for us to relocate...anywhere.

Please do not approve the Terra-Gen Campo & Torrey wind projects as proposed. These turbines are too large and too close to existing homes on and off reservation lands.

Respectfully,
Robert and Marie Morgan
2912 Ribbonwood Rd, Boulevard, CA

Hall, Harold <harold.hall@bia.gov>

[EXTERNAL] Campo Wind Scoping Comments

1 message

michele strand <michelestrand@yahoo.com> Fri, Dec 21, 2018 at 12:16 PM
To: "harold.hall@bia.gov" <harold.hall@bia.gov>, "bronwyn.brown@sdcounty.ca.gov" <bronwyn.brown@sdcounty.ca.gov>, Donna Tisdale <tisdale.donna@gmail.com>

Hello,

I fully support and endorse the comments submitted by the Boulevard Planning Group dated December 20, 2018 both as a member of the Group and as an individual property owner.

My friends who live close to the existing turbines on the north side of I-8 are experiencing many of the problems described in the comment letter. My household is also being negatively affected.

These turbines, if built, will further drive people and animals away from the area. I moved to Boulevard 14 years go to respect the land, be near nature, and to enjoy quiet starry skies. The constant sound of a never-landing jetliner and red blinking lights all night long is life-changing.

Please do not build them.

Respectfully submitted,
Michele Strand

Petition to oppose Terra-Gen's 90 new 586 ft tall 4 MW turbines and new high-voltage line planned for about 4,500 acres of Campo Reservation (252 MW Campo Wind) and private ranch land in Boulevard (126 MW Torrey Wind) & Boulder Brush Gen-tie line. It is one big connected project--not 3 separate projects! Tribal vote to approve lease was allegedly illegal--not properly noticed for vote. Most jobs will go to out-of-area contractors and labor—not locals.

Petitions for Campo Wind are due Dec 21, 2018. Send to harold.hall@bia.gov or mailed to: Amy Dutschke, Reg. Dir., BIA, 2800 Cottage Way, Sacramento, CA 95825 (Circulated by non-profit Backcountry Against Dumps as a public service)

Petition summary and background	This petition is directed at decision makers at the Campo Band, Bureau of Indian Affairs, Dept. Of Interior, San Diego County, California Public Utilities Commission, and the general public who may think turbines are benign.
Action petitioned for	We, the undersigned, are concerned citizens who urge our leaders to act now to deny Terra-Gen's massive wind turbine projects based on significant, cumulative and disproportionate adverse impacts to: public health and safety, sleep deprivation & stress-related illnesses; noise, low-frequency noise, infrasound & vibrations; increased fire risk & insurances costs; loss of scenic landscapes &property values; light and electrical pollution; well water; wildlife; pets and livestock& habit. Turbines are planned far too close to homes & roads. Existing turbines around the world generate complaints related to the impacts stated above, basically making homes toxic and families sick. Homes have been abandoned and bought out. ***Courts and public agencies around the world are finally starting to recognize that industrial wind turbines do impact health and property values.*** **STOP THE TURBINES!**

Printed Name	Signature	Address	Comment	Date
Evangeline Adkins	Evangeline MAdkins	2492 Tierra Heights Rd 91905	No Wind Turbines	12/20/2018
Heather J Robbins	Heather Robbins	2492 Tierra Heichts Rd 91905	NO Wind Turbines	12/20/2018

Hall, Harold <harold.hall@bia.gov>

[EXTERNAL] REGARDING: CAMPO WIND PROJECT-EIS SCOPING COMMENTS

1 message

Ron Hynum <rhynum@camft.org>
To: "Harold.hall@bia.gov" <Harold.hall@bia.gov>
Cc: "Bronwyn.Brown@sdcounty.ca.gov" <Bronwyn.Brown@sdcounty.ca.gov>

Thu, Dec 6, 2018 at 9:18 AM

I strongly oppose the new 252 MW Campo Wind Project that is proposed for most of the ridgelines on the Campo Reservation. Turbines are planned far too close to tribal homes and to private homes within the impact zone of several miles. There is not enough room for appropriate set-backs to protect public health and safety.

The 60 proposed 4.2 MW turbines are some of the largest available and are reported to be 586 feet tall--taller than San Diego's tallest sky scraper! They will dominate and degrade mostly natural landscapes and visual resources and habitat, and will significantly and cumulatively increase noise, electrical, and light pollution. Bigger turbines generate more low frequency noise and vibrations that will travel even farther out from the project than the existing 2 MW Kumeyaay Wind and 2.3 MW Tule Wind turbines.

Major concerns with this project include but are not limited to the following:

Noise, low frequency noise, vibrations, sleep disruption, adverse impacts to public health and well-being; increased fire risk, light pollution, electromagnetic interference including cell service; visual impacts including red lights and shadow-flicker; loss of quality of life and wildlife; loss of property values and personal investments; impacts to groundwater resources and wells during and after construction; increased traffic and road damage; removal of mature oak trees along project access routes to accommodate turbine transport; new overhead 230kV high voltage lines; disproportionate adverse impacts related to numerous wind turbine projects located in our predominantly low-income area, including Kumeyaay Wind, Tule Wind, Energia Sierra Juarez Wind, and Terra-Gen's proposed 30-turbine 126 MW Torrey Wind project that is connected to this proposed Campo Wind Project.

The existing Kumeyaay Wind, Tule Wind, and Ocotillo Wind turbines have already been documented as generating low-frequency noise, vibrations and electromagnetic interference at impacted homes up to several miles away. Residents impacted by those projects, and others around the world, complain of noise, vibrations, sleep deprivation, noise induced stress and anxiety, electrical interference, and related adverse health impacts including cancer. Some homes near turbines have been abandoned and some homes have been purchased in response to lawsuits filed against the turbine owners/operators.

Please add my name to the list to be notified of future meetings and opportunities to submit comments on the Draft and Final Environmental Impact Statement/Environmental Impact Report.

Thank you,

Ron Hynum

39548 Opalocka Rd

Boulevard, CA 91905

Disclaimer

Hall, Harold <harold.hall@bia.gov>

[EXTERNAL] Campo Wind Turbines

1 message

rosetapia4444 <rosetapia4444@gmail.com> Wed, Dec 19, 2018 at 12:24 PM
To: harold.hall@bia.gov

Mr. Hall,

We recently purchased our home here in Tierra del Sol a subdivision of Boulevard California bordering Campo and Mexico. We chose our home because of the view, peace and quite. Its a gorgeous rural setting. Very scenic and we love our panoramic view.
We have recently been informed that there is a plan to put in these giant 586 foot tall turbines lined up on the N.W., W., & S.W. side of our property all within a 3/4 mile from our front door, and experts say they should be at least two miles from our front door.
Our equity in our home would plummet, although we never plan on selling we think that you would agree that no matter what value we have on our home now, it would plummet!!
I am not a healthy woman Mr. Hall, but according to what Ive read about these turbines they have a definate impact on our health, and also our livestocks health.
We are opposed to these turbines being installed please please consider the public voice. Consider our voice please no turbines.
May Jesus bless your day
Robert Laguna
Rose Tapia 619-450-9979
1237 Tierra Real Lane
Boulevard California 91905

Sent from my MetroPCS 4G LTE Android Device

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Nancy Good **DATE:** 12-

ADDRESS: PO Box 1165, Boulevard, CA

COMMENTS:

* you did not let the community Know about this meeting and what the plans are.
* How untruthful. You tell us we have till 9 & will close @ 7. Nice!
* ~~How~~ you only gave us 3 min to oppose you. When you are going to ruin us & our property value.
* you gave us VeRy Little information.
* What about the animals?

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: CHARLES B. GOOD **DATE:** 6-DEC-18

ADDRESS: 37649 OLD HWY 80, BOULEVARD CA. 91905

COMMENTS:

I SMELL SDG&E ALL OVER THIS SDG&E WANTS TO DESTROY OUR LIVES & PROPERTY VALUES WITH OUT ANY COMPENSATION FOR OUR LOSS.

IF SDG&E & TERRA GEN WANT TO DESTROY OUR LIVES AND PROPERTY VALUES THEN BUY OUT ALL PROPERTY AT FULL MARKET VALUE PLUS 25%

From: Benjamin Good
35252 Old Hwy 80
Pine Valley, California 91905

REGARDING: CAMPO WIND PROJECT-EIS SCOPING COMMENTS

I strongly oppose the new 252 MW Campo Wind Project that is proposed for most of the ridgelines on the Campo Reservation. Turbines are planned far too close to tribal homes and to private homes within the impact zone of several miles. There is not enough room for appropriate set-backs to protect public health and safety.
The 60 proposed 4.2 MW turbines are some of the largest available and are reported to be 586 feet tall--taller than San Diego's tallest sky scraper! They will dominate and degrade mostly natural landscapes and visual resources and habitat, and will significantly and cumulatively increase noise, electrical, and light pollution. Bigger turbines generate more low frequency noise and vibrations that will travel even farther out from the project than the existing 2 MW Kumeyaay Wind and 2.3 MW Tule Wind turbines.

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Please add my name to the list to be notified of future meetings and opportunities to submit comments on the Draft and Final Environmental Impact Statement/Environmental Impact Report.
Thank you.

From: Nancy Good
Subject:
Date: December 6, 2018 at 1:56 PM
To: ngood81173@aol.com

From: Nancy Good
PO Box 1165
Boulevard, CA 91905

REGARDING: CAMPO WIND PROJECT-EIS SCOPING COMMENTS

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Thank you.
Nancy K Good

From: Charles Good
PO Box 1165
Boulevard, CA 91905

REGARDING: CAMPO WIND PROJECT-EIS SCOPING COMMENTS

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Please add my name to the list to be notified of future meetings and opportunities to submit comments on the Draft and Final Environmental Impact Statement/Environmental Impact Report.
Thank you.

Charles B. Good
6 DEC, 18

PUBLIC SCOPING MEETING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

SIGN IN SHEET

Name	Address	Email
LISA GOVER	36190 CHURCH RD, SUITE 4	lgover@campo-nsn.gov
Byron Polen	P.O. Box 1124 Boulevard	MTNmototrav@aol.
Ron [illegible]	461 Kumeyaay Rd Campo CA 91906	[illegible]@gmail.com
Bradley Downes		bdownes@bdrlaw.com
Bronwyn Brown	County of San Diego 5510 Overland Ave	bronwyn.brown@sdcounty.ca.gov

PUBLIC SCOPING MEETING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

SIGN IN SHEET

Name	Address	Email
Ralph Goff	Campo	RGoff@Campo-NSN.Gov

PUBLIC SCOPING MEETING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

SIGN IN SHEET

Name	Address	Email
H. Paul Cuero	36690 Hwy 94 Campo Ca 91906	
Annah Ceballos	37646 Williams Rd., BLVD, CA 91905	aceballos0@aol.com

PUBLIC SCOPING MEETING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

SIGN IN SHEET

Name	Address	Email
Nancy Good	PO Box 1165 Boulevard, CA 91905	nancyKgood@gmail.com
DONNA & ED TISDALE	PO BX 1275 BOULEVARD	tisdale.donna@gmail.com
Ron Hynum	39548 OI'ROCKIA Rd Boulevard CA	Ron@CAMFF.ORG
Carmen Lucas AKA Gomy (Please mail info)	37855 High Pass Boulevard CA 91905; PO Box 1452 Boulevard CA 91905	wildhorsesrunning@yahoo.com
Michelle Cuero	4011 Kumeyaay Rd Campo, CA 91906	rscuero@gmail.
[illegible]	36651 HWY 94	
Ken Wagner	11455 El Camino Real, San Diego, CA 92130	
Ashley Richmond	11455 El Camino Real San Diego CA	
Clifford Caldwell	P.O. Box 710, El Centro, CA 92244	pincal@sbcglobal.net
Concha Caldwell	P.O. Box 710, El Centro, CA 92244	pincal@sbcglobal.net

PUBLIC SCOPING MEETING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

SIGN IN SHEET

Name	Address	Email
Benjamin Asad	35252 Old Hwy 80 Pine Valley CA	allgoodworks@gmail.com
Petra Campos	4801 Kumeyaay Rd Campo CA 91906	petracampos6@gmail.com

PUBLIC SCOPING MEETING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

SIGN IN SHEET

Name	Address	Email
Steven Cuero	36810 church rd Campo ca.	none
CHARLES GOOD	P.O. BOX 1165 BOULEVARD CA	CHARLIEBROWN53@YAHOO.com
Michele Strand	PO Box 1424 Blvd USA	michelestrand@yahoo
Mark Ostrander	43577 Old Hwy 80 Jacumba Ca. 91934	clasictraclayer@Att.Net
Greg Kazmer	5510 Overland San Diego CA 92123	gregory.kazmer@sdcounty.ca.gov
Marcus Cuero	36616 Hwy. 94 Campo CA 91906	nadone05@gmail.com
BARRANCO & ZAKAR	1572 Tierra Del Sol, BL. 91905	Themightyco@gmx.com

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

December 6, 2018. 6pm

SPEAKER NAME: Clifford Caldwell

Note: Each speakers has a 3 minutes in order to allow all speakers to be heard. Please be respectful of everyone's time. Thank you.

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

December 6, 2018. 6pm

SPEAKER NAME: Benjamin Good

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PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

December 6, 2018. 6pm

SPEAKER NAME: Michelle ~~Cuero~~ Cuero

Note: Each speakers has a 3 minutes in order to allow all speakers to be heard. Please be respectful of everyone's time. Thank you.

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

December 6, 2018. 6pm

SPEAKER NAME: Nancy Good

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PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

December 6, 2018. 6pm

SPEAKER NAME: Carmen Tavarie AKA Carmen Gomez

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PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

December 6, 2018. 6pm

SPEAKER NAME: Mark Ostrander

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PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

December 6, 2018. 6pm

SPEAKER NAME: Lorrie Ostrander

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PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

December 6, 2018. 6pm

SPEAKER NAME: DENNIS LARGO

Note: Each speakers has a 3 minutes in order to allow all speakers to be heard. Please be respectful of everyone's time. Thank you.

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

December 6, 2018. 6pm

SPEAKER NAME: CHARLIE GOOD

Note: Each speakers has a 3 minutes in order to allow all speakers to be heard. Please be respectful of everyone's time. Thank you.

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

December 6, 2018. 6pm

SPEAKER NAME: DONNA TISDALE

Note: Each speakers has a 3 minutes in order to allow all speakers to be heard. Please be respectful of everyone's time. Thank you.

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CA.

December 6, 2018. 6pm

SPEAKER NAME: ED TISDALE

Note: Each speakers has a 3 minutes in order to allow all speakers to be heard. Please be respectful of everyone's time. Thank you.

COMMITTEE ON ARMED SERVICES
COMMITTEE ON EDUCATION AND THE WORKFORCE
COMMITTEE ON TRANSPORTATION AND INFRASTRUCTURE
CHAIRMAN, SUBCOMMITTEE ON THE COAST GUARD AND MARITIME TRANSPORTATION

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Duncan Hunter
U.S. House of Representatives
50th District, California

January 10, 2019

Mr. Dan Hall
Acting Chief, Division of Environmental Cultural Resource Management and Safety
Bureau of Indian Affairs
1849 C Street, NW
MS-4620-MIB
Washington, DC 20240

Bronwyn Brown, Project Manager
San Diego County Planning & Development Services
5510 Overland Ave
San Diego, CA 92123

RE: CAMPO WIND EIS SCOPING COMMENTS

Dear Chief Hall and Manager Brown:

I am writing regarding requests you have received from the Boulevard Planning Group, Backcountry Against Dumps, Donna Tisdale and others who are seeking a 30-45 day scoping comment extension as it pertains to the Campo Wind Energy Project. As you may know, concerns have arisen regarding inadequate public notice and limited project mapping information provided to interested parties before the deadline of 12/21/18.

Based on information submitted by the involved stakeholders, there appears to be justification to view the proposed project as part of a larger, overall endeavor. In such case, a joint NEPA/CEQA review to address the existing, proposed, pending, and foreseeable energy and infrastructure projects on and around the Campo Reservation and surrounding Boulevard community, including the related impacts to residents and local resources, may be warranted. I respectfully request an opportunity for my constituents to be heard further on this important matter.

Thank you in advance for your consideration. I would appreciate a response from your office(s). If you have any questions or require additional information, please do not hesitate to contact me directly, or Michael Harrison in my office, at (619) 448-5201.

Sincerely,

Duncan Hunter
Member of Congress

DH/mrh

Cc: Pacific Regional Director Amy Dutschke, Bureau of Indian Affairs
Supervisor Dianne Jacob, County of San Diego

Clifford C. Caldwell and Concepcion G. Caldwell
P. O. Box 710
El Centro, CA 92244

December 21, 2018

Dan (Harold) Hall, Acting Chief
Division of Environmental, Cultural Resource Management and Safety
Bureau of Indian Affairs
<harold.hall@bia.gov>

Re: EIS Scoping Comments, Campo Wind Project, San Diego County, California

Dear Mr. Hall,

We attended the December 6, 2018 EIR Public Scoping Meeting held at the Campo Indian Reservation Tribal Hall in Campo, California. As requested in your original Notice of Intent, we are commenting in writing as to our concerns about the proposed Campo Wind Project. We own property to the north of Interstate 8, to the east of the proposed Campo Wind Project and to the west of Ribbonwood Road in Boulevard, California.

In reviewing the map provided to us for the proposed Campo Wind Project, we would clearly be looking directly at any proposed turbines located on the Reservation north of Interstate 8. The reason we can't be more specific about where we are located in proximity to the projected turbines, is that the map provided as part of the scoping process is totally "inadequate" to determine the potential location of turbines or project sites. One of the first statements at the scoping meeting was that we would be provided with a more detailed map of the proposed project and the surrounding areas. We have yet to see an enhanced map.

We mistakenly thought that the purpose of the scoping meeting would be to further inform us as to the relevant facts about the proposed Campo Wind Project. However, at the meeting it became clear that the individuals handling the scoping meeting either had no idea of the project's specifics, or they did not want to provide them, especially since they could not even identify Ribbonwood Road in relation to their own map. For your information, Ribbonwood Road is the main access route to Boulevard properties north of Interstate 8 and directly east of the project. It is extremely hard to discuss a project, when it is not properly described other than to state it could involve up to 60 turbines over a "study area" covering approximately 2,200 acres on the Campo Indian Reservation.

As to the project, it would be nice to know where they propose to locate the wind turbines (of up to 586 feet in height), the temporary staging and construction trailer areas, the operations and maintenance building, the new access roads, the temporary concrete batch plan, or any other proposed facilities. Will they be located north or south of Interstate 8, or maybe in Jacumba, CA seven miles away?

It appears that providing any such meaningful information for the scoping meeting was deemed unnecessary as it appeared that those individuals running the scoping meeting weren't really seeking our input. The main preoccupation of those running the scoping meeting was to make sure participants didn't speak over the allotted period of time of three (3) minutes, as if it would hinder their process.

They didn't appear to be taping the meeting, we assume for the purpose of being able to filter out information they did not want to hear. The person transcribing the scoping meeting would start to yell in the middle of participant's comments hat "you are going too fast", while the person leading the meeting would keep telling you that your "time is running out". Not that the allotted time of three hours (6:00 p.m. to 9:00 p.m.) would be jeopardized by letting anyone speak for an extra minute. This is especially true in view of the poor turnout to the meeting and the "haste" of the individuals handling the process to depart the premises. The scoping meeting was over in record time as it completed by 7:00 p.m., in less than an hour of the scheduled three (3) hour period.

Because of the extremely poor manner in which the scoping meeting was handled, we looked up 40CFR 1501.7 to determine the purpose of the scoping meeting. As part of the scoping process the lead agency shall:

> "Invite the participation of affected . . . and other interested persons (including those who might not be in accord with the action on environmental grounds."

It was apparent from the lack of local participation that the lead agency did little, if anything, to get anyone to attend the scoping meeting. If the purpose of a scoping meeting is to seek input, then the lack of "notice" becomes very important. A number of the people who spoke at the meeting stated that they would not have known about it except for the statement of one of our local individuals.

We would suggest that if you have a "proposed project" that encompasses over two thousand two hundred acres and cannot get more than about ten (10) individuals to speak, then either the lack of appropriate notice was intentional, or those in charge are simply "incompetent" at their job and should be replaced.

Therefore, we would suggest (or in the alternative demand) an appropriately "noticed" scoping meeting for which project information is available and concerns can be legitimately addressed. I would point out that the lead agency's overwhelming description of the project is contained in a full page (plus 2 lines) consisting of double-spaced information that generally states as follows:

> **"The project would include the generation of up to 252 MW consisting of up to 60 turbines. The project study area covers approximately 2, 200 acres on the Campo Indian Reservation"**

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December 21, 2018

The scoping meeting certainly did not address the following:

(a) Where will the wind turbines be located?
(b) Where will the underground electrical collection system be located?
(c) Where will the new 230 KV overhead generation transmission line be located?
(d) Where will the three permanent meteorological towers be located?
(e) Where will the temporary material laydown area be located?
(f) Where will the temporary staging and construction trailer areas be located?
(g) Where will the operations and maintenance building be located?
(h) Where will the new access roads be located?
(i) Where will the temporary concrete batch plant be located?

We guess one could claim that we are showing a total lack of ingenuity, because we can't guess where these items are going to be placed. However, location is very important. We would unequivocally state that we would have no objections to the project, if it were "all" going to be located on two (2) acres of the most northerly portion of the Campo Reservation.

We could also equate this scoping situation to informing you that we are going to have a scoping meeting about the "repair of our car", then ask you to comment about our proposed project. You might want a little more information!

Since we have had "no" opportunity to participate in a serious scoping meeting, we are only left to guess! Therefore, we will guess as follows:

<u>Direct View of the Project</u>
Will we have a direct view from our properties of the proposed wind turbines, the batch plant, the underground electrical collection system, the new 230 KV overhead generation transmission line, the permanent meteorological towers, the temporary material laydown area, the temporary staging and construction trailer areas, the operations and maintenance building, the new access roads and/or the temporary concrete batch plant? During what hours will these facilities be under construction or be in operation? These facilities will clearly result in increased noise, air pollution, visual impediments, and other types of disturbances from graders, water trucks, backhoes, excavators, drilling rigs, concrete trucks, cranes, dump trucks, turbines, towers, etc. How will these increases in noise and light be mitigated as part of the project?

<u>Water Resources</u>
One of our primary concerns is the issue of water resources in the local area. Will the project be using local water resources? How many water wells are located on their properties, and will they be putting in any more wells? We are concerned about their use of water to the detriment of the surrounding land owners to benefit these new wind-generating companies. A failure of wells on adjacent non reservation properties or a contamination of the local water sources would be catastrophic. Is the use of water going to affect the natural ponds and any wetlands in the area? In regards to the water resources, we need to know:

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(a) What water wells, and/or water facilities, does the Campo Wind Project intend to use for their project and from what depth (and what volumes of water) will they be pumping from each of these wells?

(b) What is the estimated amount of groundwater consumption by the proposed Campo Wind Project, the Torrey Wind Project, as well as any other proposed projects in the area? It is the "combined" projects that will ultimately impact the water resources in the area. However, every project seems to be discussed separately so as to avoid their "combined" impact on the local water resources. If we have ten (10) projects in the area, each taking 20-acre feet of water that is two hundred (200) acre feet of water, not 20-acre feet. It is their "combined" impact that should be the basis of the study, not the separate impact of each project. Therefore, will the combined water uses of all projects be studied (and disclosed to the public) for purposes of the Campo Wind Project?

(c) There is the initial use of ground water for construction, building, etc., and then there is the ongoing use of water for any continuing project activities. The initial construction period will involve the greater use of local water resources in the short term. We need to know what each of these activities will entail and what their water uses will involve and their "combined" effect on the water table and the water resources in the area.

(d) What are the estimated impact of these water uses on the neighboring properties, the animal life (including bird and animal habitats)? The loss of water sources, in the event surface waters dry up, has a direct effect on the birds (hawks, peregrine falcons, prairie falcons, owls, golden eagles, red tail hawks, quails, wood peckers, sparrows) and smaller animals such as ground squirrels, rabbits, mice, rats, etc., including any animals referenced by the County of San Diego (or the Federal government) as sensitive species and/or that have historically been detected on site or in the local area. Also impacted are the larger animals such as bobcats, mountain lions, coyotes, racoons, etc. As noted in the release dated December 30, 2015 by the USDA, the U. S. Forest Service pointed out that bird nesting in areas throughout the Cleveland National Forest are closed to the general public each year in order to protect certain raptors due to declines in their populations resulting in the need for added protection for these species.

(e) What is the estimated impact of this water use on the oak woodlands, grasslands, chaparral and any marshes located on the neighboring properties? As you know, the local trees have been stressed by the drier climate over the past few years. Is the use of ground water going to endanger the remaining vegetation and trees that have managed to survive, or can we expect additional tree and vegetation losses from these various projects?

(f) The Bureau of Indian Affairs (the lead agency for the project) needs to review the current and possibly future projects in the Boulevard/Campo area. As such, the proposed impacts of all of these projects "combined" should be included as part of the water studies, whether within the jurisdiction of the Bureau of Indian Affairs and/or the County of San Diego, or whether they are located on County property, BLM grounds, or on the Reservation. The studies should include the Campo Wind, Tule Wind, Kumeyaay Wind and any other projects in the surrounding areas.

(g) What is the effect of these wind turbines on the local climate? To what extent are these whirling blades responsible for redirecting the wind and further drying up the surrounding land mass? Will the numerous revolving blades affect the plant growth and therefore the ability of the ground to absorb and retain moisture?

(h) If there are resulting water shortages due to the Campo Wind Project, are the beneficial owners of the project going to be responsible for providing water to the surrounding properties, the individuals living thereon, the trees, vegetation and plant life? If not, then to what extent is the risk of water shortages being dealt to the local land owners?

(i) How will the uses of water by the Campo Wind Project affect the potability of the remaining water resources in the local area?

(j) Will water run-off bring potential water pollution to the surrounding properties to the proposed project? If so, what type of pollution will it be?

(k) What potential water pollutants will be used as part of the Campo Wind Project, and can they become part of the water run-off from the project?

(l) How will the clearing of large areas of the Campo Wind Project affect the drainage patterns to the properties surrounding the project, including the adjacent non project properties? How will these problems be addressed, and who will assume the attendant risks associated therewith? Historically, the County of San Diego was concerned about flooding along Ribbonwood Road and discussed with residents the need for a bridge over the road's lowest lying areas. In addition, does the Campo Wind Project have the necessary easements to access all of their reservation properties or will they be using Ribbonwood Road?

(m)In order to know the effects of the project on the local water basin, we need to know the estimated amount of local groundwater in the proposed project area and the surrounding areas.

(n) To what extent is the local groundwater typically replenished by the rain, etc. in our area and is that reflected as part of the applicant's plan of use?

(o) If our water wells and the wells of other surrounding property owners stop producing sufficient water flow, how does the Bureau of Indian Affairs and the County of San Diego intend to deal with such problems? Who will have a priority to the use of any local water resources. Does the Bureau of Indian Affairs or the County of San Diego have an existing plan of action in place to deal with such problems, or is everyone on their own when it comes to water?

Intrusion of Noise, Vibrations and Infrasound

One of our primary concerns is that the proposed development of the adjacent project property will cause substantial intrusions of noise and vibrations to surrounding properties. How close will the proposed turbines sit to our properties. In the scoping information, we can only assume that the proposed wind turbines would have a proposed height of up to 586 feet (not 361 feet in hub height). There is little doubt that the proposed turbines will create substantial noise, vibrations and infrasound.

As previously stated, will any of the surrounding property owners have a direct line of sight to the proposed wind turbines, the batch plant, the underground electrical collection system, the new 230

KV overhead generation transmission line, the permanent meteorological towers, the temporary material laydown area, and the temporary staging and construction trailer areas, the operations and maintenance building, the new access roads and/or the temporary concrete batch plant. Also, you will find that all the wind turbine noise will reverberate south, east and west to the adjacent properties. As part of the project will they be removing oak trees and shrubs from the project property that might block some of the project noise?

The wind turbines, vehicles, batch plants and other activities on the reservation properties are clearly going to increase the ambient noise in the vicinity, both during the day and at night. In regards to the noise and vibration factors of the proposed project, we need to know:

(a) What is the volume and amount of noise, vibrations, etc. that will be created by the wind turbines?

(b) What is the combined effect of such noises from more than one (1) source (i.e from sixty wind turbines, or other activities)? As with all types of noise, any wave patterns or combination of sound frequencies or vibrations crossing onto adjacent properties can accumulate from separate sources and result in a larger pattern, volume, or frequency of noise/vibration.

(c) What activities will be carried on at the locations of the proposed wind turbines, the batch plant, the underground electrical collection system, the new 230 KV overhead generation transmission line, the permanent meteorological towers, the temporary material laydown area, the temporary material laydown area, and the temporary staging and construction trailer areas, the operations and maintenance building, the new access roads and/or the temporary concrete batch plant and what noises, smells, air pollution, etc. will they create?

(d) During what hours will these wind project activities take place? Will there be noises and air pollution from the adjacent properties over six (6), eight (8) or ten (10) hours a day? Will these activities be during the week, or will they be occurring over the weekends and holidays?

(e) What is the effect of the rotating turbine blades (and the turbine noise), including the low frequency noise and infrasound, on the bats, owls, hawks, falcons, golden eagles, woodpeckers and other bird populations? If we lose any of these animals will we have potential increases in the mosquitos, bugs, moles and rodents in the area resulting from the changes to the ecosystem for these species (or other species)? If there is a decrease in these predators, are we going to have a substantial increase in their prey? For example, if we have a decrease in the hawks, will we see a substantial increase in rodents and ground squirrels?

(f) Will there be an exhaustive study of the ecosystem (animals, birds, plants, etc.) prior to the proposed project, so we have a baseline for comparison, and so we can determine the actual effects of the project?

(g) Have there been any studies of the ecosystems in the local or surrounding areas that are available for our review in order to determine the effects of these wind turbines and the supporting infrastructure? Have there been any studies (either before or after) for the

Tule Wind or Kumeyaay Wind projects that are available? If there have been such studies, are the results currently available to the rest of us, and how do we get access to them?

(h) What are the effects of these noises, including low frequency noises and infrasound on the local bats that help control the mosquitos and bugs in the local area? First, have they identified and/or studied the local bat populations and their habitats? We are lucky to have substantial bat populations in the local area. They help control the mosquitos and bugs which can become a substantial problem both during the day and at night. Has there been, or will there be, any attempt to ensure the habitat for bats and preserve any bat colonies located on the Campo Wind properties or the surrounding areas? To what extent will the Campo Wind Project result in the further degradation of the natural habitat for any existing or future bat populations? Has there been any study of the local bat populations and the benefits they provide by consuming insects (almost up to their body weight in insects each night) that are a nuisance to humans? Is the California leaf-nosed bat [a sensitive species of concern that is the subject of monitoring in other areas] located in the area? These species are currently monitored by the BLM in the adjacent areas of Imperial County. Are California mouse-eared bats located in the area? What problems are caused to the bat population by large volumes of noise masking certain types of sounds? Will this result in larger numbers of bats dying, and does the Bureau of Indian Affairs and/or the County of San Diego have a plan of action in place to deal with such a contingency?

(i) What are the effects of wind turbine noises, including low frequency noises and infrasound, on the bird population in the local area? What is the effect of chronic noise exposure on communication calls and other bird vocalizations? What is the masking effect of sixty (60) wind turbines on the local bird population? These masking effects on the bird population should be considered as part of the cumulative impacts of the Campo Wind project on the local wildlife. The same is true of any other animals in the area that rely on their hearing to avoid predators or to find prey. In other words, what is the effect of the wind facilities on the local ecosystem?

(j) It is my understanding that the County of San Diego was going to update any studies as to the effects of wind turbines on the health of individuals. Is there such a study and, if so, when will it be reviewed as part of the Campo Wind Project? There are a number of studies that discuss wind turbine noise exposure and suspected health-related effects on individuals. This includes low-frequency noise and infrasound. They include sleep disturbance, annoyance, etc. As part of the review of the Campo Wind Project, does the Bureau of Indian Affairs intend to respond to questions about the suspected health-related effects of exposure to wind turbine noise, vibrations, infrasound, etc? Will the Bureau of Indian Affairs actually study and reflect on the health consequences to the surrounding population (either human or animal) resulting from exposure to wind turbine noise (including vibrations and infrasound) as part of this process? Does low-frequency sound exposure increase with turbine size, and is it related to wind speed in

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December 21, 2018

the area? In addition, are there other suspected health-related effects that may need to be outlined and studied as part of the proposed Campo Wind Project?

(k) In the event that excess noise, vibrations and infrasound occur as a result of the wind turbines, what plan of action does the Bureau of Indian Affairs have in place to discover and deal with such problems? For example, if the noise, vibrations and infrasound are found to be excessive, will the Bureau of Indian Affairs discover and deal with the problem, or will the surrounding landowners be left to deal with the problem? Who is required to police these problems and who is entitled to the related information and records? Does the Bureau of Indian Affairs have access to any records reflecting the amount and types of noise generated by the existing Tule Wind and Kumeyaay Wind projects that might aid their analysis of the Campo Wind project?

Electromagnetic Interference

Will these proposed electrical facilities and electrical generators cause problems with our homes and properties as a result of electromagnetic interference? What is the overall effect of these proposed electrical facilities? Will they cause problems related to electromagnetic induction, electrostatic coupling or conduction? What problems to the surrounding properties will be caused by electromagnetic interference and are there any health-related issues?

Air Pollution in the Area

This is a large project covering approximately 3.43 square miles of area. As a result of numerous roads, vehicles, construction projects, etc., there will be a substantial problem relating to air pollution. The entry roads throughout the area of the Campo Wind Project cover a number of dirt roads that are notorious for the amount of dust that is kicked up by the vehicles traveling them. As the amount of vehicle/equipment traffic increases, there will be a large incremental increase in the amount of dust that is generated that will directly affect the homeowners and others near to or adjacent to the Reservation. Does the Bureau of Indian Affairs have a plan for dealing with these roads and the increase in the air pollution?

In addition, to what extent will the proposed wind turbines, the batch plant, the underground electrical collection system, the new 230 KV overhead generation transmission line, the permanent meteorological towers, the temporary material laydown area, and the temporary staging and construction trailer areas, the operations and maintenance building, the new access roads and/or the temporary concrete batch plant add to increases in air pollution? What types of mitigation will be required of the proposed project to minimize any increases in air pollution?

Light Pollution in the Area

In addition, we question the amount of light pollution that the adjacent owners will have to deal with as a result of the proposed project. At night the wind turbines, vehicles, batch plants and other activities are clearly going to increase the ambient light in the local vicinity. Will the proposed project somehow be required to minimize their light footprint during the evening hours? This will be affected by their hours of operation and the activities they are allowed to undertake after sunset. During what hours will the project be allowed to operate? To what extent will these activities and any resulting light pollution therefrom affect our surroundings at night?

There are those who do stargazing at night. To what extent will these lights interfere with stargazing or the use of telescopes to see the stars and/or our ability to see the stars, planets and the Milky Way. Is there any limitation of the types of lights that the Campo Wind Project can use in the area? Has the problem of light pollution been studied or dealt with by the Bureau of Indian Affairs as part of the Campo Wind project?

Assessment of Fire Risks and Related Planning

What is the effect of the proposed Campo Wind Project on the local fire risks in our area? In the event of a fire, who will be underwriting the fire risks of the proposed project (i.e. if there are injuries to the surrounding properties or individuals)? What increased risk of fire will the local Boulevard/Campo community be facing by the addition of these numerous electrical generating and distributing facilities? Will the Campo Wind Project assess such a fire risk to its facilities and to the local community, and who will bear the responsibility for any damages resulting from any fire caused by the proposed Campo Wind Project? To what extent will the project be protecting their neighbors against such risk? What is the structure of the Campo Wind Project going to be in the future? In the event of any fire losses (resulting from the activities of the Campo Wind Project in generating and distributing electrical power), to what extent are we going to be able to look to the Campo Wind Project (as a whole) to reimburse the surrounding homeowners/landowners from any resulting fire damages (or loss of life), or will the ownership of the project be divided into various operating entities of such small value as to make such a discussion irrelevant?

Visual Impacts To the Area and Effects on Residential Property Values

We are dealing with sixty (60) huge wind turbines each up to 586 feet tall (a 361-foot hub height with three 225-foot blades spinning with a diameter of 450 feet) and each almost one-half the height of the Empire State Building. These behemoths will clearly hurt the views and reduce the property values for those remaining "residential" property owners in the area. These detrimental effects should be addressed as part of the scoping process.

Inappropriate Division of a Single Overall Wind Project

One of the issues not really discussed is the manner in which the various parties, the Bureau of Indian Affairs, the BLM and the County of San Diego seems to piece a number of proposed projects separately so as to avoid their "combined" impact on the water resources, noise impacts, etc. It is clear that Terra-Gen's Campo Wind project and the Torrey Wind project are connected and should be reviewed as one (1) project. They have planned to use the same proposed substation and have lines that have been planned to connect both projects together. The issue of the proposed Major Use Permit for the construction and operation of the Boulder Brush Gen-Tie line and Substation/Switchyard Facilities is one such example. As per our review, the Boulder Brush facilities come directly across the Torrey Wind project and seem to end at the southwest end of their properties. As reflected in the MUP, access for this project is also to be provided by way of

Ribbonwood Road. Therefore, the various impacts discussed herein are also applicable to this additional Boulder Brush MUP. There are discussions about construction of additional temporary and permanent access roads (Gen-Tie line access roads 16 to 20 feet wide that will remain as part of the project), additional improvements to existing roadways, installation of 32 steel poles up to 150 feet high, additional staging areas (strategically placed?) and a temporary concrete batch plant, etc. The problem is that this Campo Wind Project line has to tie into some other type of service or project that is not even being discussed as part of the project. The cumulative effects of these other projects have to be studied together as part of the Campo Wind Project and the Torrey Wind project.

Size of Wind Turbines and Location Thereof.
The wind turbines that are being planned are huge (too big for the local area). In addition, the wind turbines and other facilities have typically been located too close to adjacent homes and landowners. What setbacks are being recommended for these wind turbines and their related facilities? It appears that Boulevard, Campo and the surrounding areas have become a dumping ground for these large wind generation projects. This is disproportionately impacting our predominately low-income rural community and does not benefit the public because of the high costs related thereto. There are other legitimate alternatives to constructing these large wind turbine projects.

Incorporation and Support of Boulevard Planning Group Comments & Back Country Against Dumps
We support any comments of the Boulevard Planning Group and Backcountry Against Dumps that may be filed as part of this scoping process. We would fully support them and would request that their project comments (and any of their supporting documents) be incorporated herein by reference.

We appreciate the opportunity to address our concerns and questions to the Bureau of Indian Affairs for purposes of their scoping of the Campo Wind Project. We would suggest, however, that pertinent information about the project be provided by the Bureau of Indian Affairs prior to the scoping process. "Due process" requires an ability to make "informed" comments or responses. We have clearly been denied that ability!

Sincerely,

Clifford C. Caldwell & Concepcion G. Caldwell

cc: County of San Diego
Boulevard Planning Group
c/o Donna Tisdale
<tisdale.donna@gmail.com>

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

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PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Andrea Najera **DATE:** 12-18-18

ADDRESS: 36500 Church rd Campo CA 91906

COMMENTS:

I am a Campo Band of Mission Indians tribal member.
I am against the Campo Wind Project for the following reasons.
Its being illegally pushed on us by tribal council.
It will cause health problems.
It will destroy the only thing we as a Nation have which is our land, Water, Air, Animals & People!
I feel tribal council needs to be investigated due to lack of information to us as the general council.

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Dennis Largo **DATE:** 12/21/18

ADDRESS: 36651 Hwy 94

COMMENTS:

I am A tribal member I do not!!! want This wind mill. Please hear our cause, we were duped into the project and most Don't want it

Signed
Dennis Largo

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BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: DAN MASON **DATE:** 12/18/18

ADDRESS: 38300 MANZANITA RD, BOULEVARD CA, 91905

COMMENTS:

I AM A TRIBAL MEMBER ENROLLED AT CAMPO RESERVATION. I AM AGAINST THE WIND TURBINE PROJECT!

[signature]

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BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Georgina Boudreau **DATE:** 12/10/18

ADDRESS: 36510 Church Rd Campo CA 91906

COMMENTS:

I am a Campo Band of Mission Indian Member
I love my reservation land, Animals and humans
I don't want it destroyed by Wind turbines
I dont think $300,000 dollars for my land
is enough to relocate if I have to.
$300,000 million Might be enough to relocate
from my own homeland.
our Chairman has had no meetings to tell
us how much money we have for a long long
time. BIA you better help us!
Investigation!!!

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BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Juanita Batey **DATE:** 12/20/18

ADDRESS: 36510 Church Road, Campo, CA 91906

COMMENTS:

I am a tribal member from the Campo Band of Mission Indians and I am against the Campo wind turbines project that has been pushed through by the executive Council. This project is takening away my right to vote and forcing me to live next to these turbines that could have adverse affects on my health. It's going to destroy our land and is a potential threat to the environment.

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From: Teresa DeGroot teresa91905@icloud.com
Subject: Boulevard windmills
Date: Dec 18, 2018 at 10:25:52 AM
To: harold.hall@bia.com ← My email to this address would not go thru?

We moved here to Boulevard to enjoy the quiet life of country living. We were willing to deal with a 3 hour round trip commute to and from work to have our peaceful life. Since moving here we have been continually threatened with windmill farms. There have been 25 placed directly North of us and uncounted ones to the Northeast. Plus 1 directly West.

The 25 to the North have effected us dramatically! (North of hwy 8)
1. They have destroyed our view of the Laguna Mountains.
2. We have had to place a large trailer to block the flashing Red lights.
3. We had to turn our bed around and away from the wall so we did not have the flashing red lights in our eyes when we sleep.
4. A constant hum from the cooling fans.
5. The damage done when they broke apart and burned. When they finally cleaned up the damaged parts we believe they were illegally dumped.
6. They appear to be continually leaking oil which does not appear to be clean energy to us.

We now understand there are plans to place more directly North of us on the South side of the 8, that would place them in our back yard! We currently have nothing between us and the hwy. We have 3 senior horses that would be drastically effected by such large scary things so close to the pasture! This is in addition to the previous 6 items we listed above which will only be closer and more of an impacted on us.

We also are very concerned about the impact on our home value, we could not sell and move because of the decline in our house value, even if we wanted to!

We are drastically opposed to the windmills that are here and to anymore being add. We understand they do not pay for them self's and are nothing but an eyesore to the residence. We also have been told that they can be dangerous to our health and we hope that anyone making the decisions about these new ones take all of this into consideration and not allow any more big businesses to invade the residence in this area.

Thank You for your consideration,
Andy and Teresa DeGroot

Sent from my iPad

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Joyce Largo **DATE:** 12/19/18

ADDRESS: 4611 Kumeyaay Rd.

COMMENTS: I don't feel like it's a good idea for these reason Wind turbines are potential threat to wildlife such as birds & bats. Deforestation to set up the farm creates an environmetal impact & the noise will effect air community.

Reg Dir ala ✓
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BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

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PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Linda Quihuis **DATE:** 12/18/18

ADDRESS: 36510 Church Road Campo 91906
Tribal ~~Campo~~ Member

COMMENTS:

I am against windmill placement on the Campo Indian Reservation. I feel these wind mills should not be placed in Residential areas on the Reservation. We already have wind mills that donot pay well. We (my Family) have no idea what will happen when that lease is up. Executive Committee Called us to an informational mtg. about new wind mills, then to my Suprise called for a vote to move on Some deal that was not available to read up on. No Regular mtgs have been called, No budgets have been made available to tribal members. We, the Campo Band of Mission Indians General Council voted NO to wind mills already in 2012.

By 12/21/18 Send to: Ms. Amy Dutschke, Regional Director, Bureau of Indian Affairs, Pacific Regional Office, 2800 Cottage Way Sacramento, CA 95825

I feel I am being forced against my will to embrace a project that will be detrimental to all inhabitants of Campo Reservation.

~~[illegible]~~ Executive Committee decided to do this project without all members of Campo Band of Mission Indians having a say in it or a vote on if they wanted it. ~~[illegible]~~ Executive Committee failed to inform all members of this project's details and why they think its a good thing.

They are purposely withholding information on this project as well as the other wind mills we already have, which is making me feel betrayed by tribal Council and I feel they are lying to the people including the surrounding community.

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

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PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: MICHELLE A. CUERO **DATE:** 12-20-18

ADDRESS: 4611 Kumeyaay Rd Campo, CA 91906

COMMENTS:

I am a member of the Campo Band of Mission Indians and I am against the proposed Campo Wind Project.

The Campo Band is experiencing political corruption.

This leadership refuses to hold required General Council mtgs to disclose status of finances to tribal members since 2012.

This leadership held an illegal vote with no quorum in April 2018 to pursue a large industrial wind turbine project.

The April 2018 meeting was noticed as informational only, but the leadership held a vote after the Chairman excused most of the tribal members who were opposed to the Wind Project leaving just their supporters to vote, YES.

Campo Wind represents a taking of tribal members property without just compensation, a form of inverse condemnation.

This leadership has failed to keep our General Council informed of our existing Kumeyaay Wind Project and the Golden Acorn Casino Wind turbine.

This tribal leadership has failed to consult our General Council or properly noticing meeting for federal action to enter lease/sublease agreement with Terra-Gen LLC for Campo Wind on our tribal lands. Our tribal leadership has failed to disclose adequate project information or a detailed map prior to federal scoping meeting held by the BIA on December 6, 2018. Our tribal leadership has failed to properly notice tribal members of the December 6, 2018 BIA scoping meeting related to federal Action. A notice was posted the day of the BIA scoping meeting on December 6, 2018 on the tribal website, But most tribal members don't have internet and our leadership knows that. Our tribal leadership is supposed to provide safe housing they failed by making our homes a toxic environment with related adverse health impacts.

Most of all, NO Landfill, No Shulluk Wind Project; No Campo Wind Project on the Campo Indian Reservation Now or Ever! We are circulating a petition to Stop the Campo Wind Project and to impeach this Dictatorship of criminals posing as Campo Tribal Leadership.

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number of pages including cover sheet: 2

attention to: Ms Amy Dutsche date: 12/21/18

company: Bureau of Indian Affairs from: Phillia H. Lowe

phone #: (916) 978-6000 company:

fax #: (916) 978-6099 senders phone #: (619) 933-2652
(916) 978-6041

comments: Tried numerous times from work to fax my comments, to no avail. Hopefully this works

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12-21-18

To: Ms. Amy Dutsche, Regional Director
Bureau of Indian Affairs, Pacific Regional Office
2800 Cottage Way
Sacramento, CA 95825

Subject: EIS Scoping Comments, Campo Wind Project
San Diego County California

From: Phillip H. Lowe
37515 Moon Valley Road
Boulevard, CA 91905

I would like to take this opportunity to address my numerous concerns relating to the Campo Wind Project.

As a Tierra Del Sol property owner/resident, and adjacent to the Campo Indian Reservation, I am *against* both sizes of wind turbines in your scope but find the smaller 2.5-megawatt turbine should be more than sufficient for their purposes.

In the provided scoping information it's stated that 60 of the 2.5 to 4.2 megawatt turbines are to be utilized. Additionally, the scope states that 252 megawatts will be generated. The only way to achieve 252 megawatts is through the use of the 4.2-megawatt turbines, which leads me to question why the scoping mentions the 2.5-megawatt turbines at all. The 2.5MW turbines are similar to the ones currently used at the Tule Wind Farm in the local region. The total output of the 2.5 MW turbines would be about 150 megawatts.

I believe the 4.2 MW turbines are *too large* for this region, and the 2.5 MW turbines might be a more viable option from a visual, ecological and health & safety aspect.

Adverse effects of the turbines:

1) Numerous on & off-reservation residents are in close proximately to the location of the proposed wind turbines.
2) Low-frequency noise has been known to expand beyond the surrounding areas, a health concern.
3) Infra-sound levels (ultra-low frequency), effect central nervous systems of people & wildlife.
4) Vibration noise caused by rotor turbulence.
5) Strobe-like intermittent shadows of visible light as the wind turns the blade.
6) Bird kill, including Golden Eagles, raptors, bats, hawks, vultures, owls, harriers, etc.
7) Danger to ground dwelling wildlife, including their displacement, death and lack of reproduction.
8) Risk of water contamination, degradation and elimination of sole-source aquafers & wells.
9) Loss of native vegetation, possibly causing landslide displacement and erosion.
10) Increased risk of wild fires, and unknown stability during potential earthquakes.
11) More effects, too numerous to mention.

I fully recognize the needs and desires of the Campo Band of Indians to generate additional sources of income. I am *very* concerned about the size of this proposed project, the negative effects mentioned above, and also the cumulative number of additional large projects surrounding our community. I appreciate your consideration.

Sincerely,

Phillip H. Lowe

Phillip H. Lowe

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Ronald R Cuero Jr **DATE:** 12/15/18

ADDRESS: 4611 Kumeyaay Rd Campo CA 91906

COMMENTS: I'm a Tribal member From the Campo Band of Mission Indians. I work for Dudek and other company's here in san Diego california. The project's I've Completed are the Ocotillo wind project, Tule wind project just to name a couple. I've seen many project's come and go. The Campo wind project is Bad for Campo! on many level's. We already have 100 tribal members who are homeless and those number's could double in the year 2019. My tribe need's help and This wind project is not it.

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PACIFIC REGIONAL OFFICE
BUREAU OF INDIAN AFFAIRS
2018 DEC 21 PM 2:28

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE 2800 COTTAGE WAY SACRAMENTO CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT. SAN DIEGO, CALIFORNIA.

NAME: Monica Garcia **DATE:** 12/11/18

ADDRESS: 294 Shasta St. #A
C.V. CA 91910

COMMENTs:

SEE ATTACHED

REASONS

AGAINST:

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Fax

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS PACIFIC REGIONAL OFFICE 2800 COTTAGE WAY SACRAMENTO CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: GREG MONTEGNA

DATE: 12-11-18

ADDRESS: 8043 hemingway
SAN DIEGO CA 92122

COMMENTs:

SEE ATTACHED

REASONS

AGAINST:

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS PACIFIC REGIONAL OFFICE 2800 COTTAGE WAY SACRAMENTO CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Rosario Valdez

DATE: 12/13/18

ADDRESS: 2515 Camino del Rio S. #240
San Diego, CA 92108

COMMENTs:

SEE ATTACHED

REASONS

AGAINST:

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: ESTRELLA OROZCO **DATE:** 12/13/18

ADDRESS: 3837 WABASH AVE #6 SAN DIEGO, CA 92104

COMMENTS:

I AM AGAINST THE PROPOSED CAMPO WIND ENERGY PROJECT. SEE ATTACHED.

BY 12/21/18 SEND TO: MS. AMY DUTSCHKE, REGIONAL DIRECTOR, BUREAU OF INDIAN AFFAIRS, PACIFIC REGIONAL OFFICE, 2800 COTTAGE WAY SACRAMENTO, CA 95825

PUBLIC SCOPING FOR PREPARATION OF A DRAFT ENVIRONMENTAL IMPACT STATEMENT TO THE PROPOSED CAMPO WIND ENERGY PROJECT, SAN DIEGO, CALIFORNIA.

NAME: Rita Ruiz **DATE:** 12/13/18

ADDRESS: 1317 5th Ave, San Diego, CA 92108

COMMENTS:

I am against, please see the attached.

Morning Star Ranch

Ed and Donna Tisdale, PO Box 1275, Boulevard, Ca 91905

Dan (Harold) Hall
Acting Chief Division of Environmental
Cultural Resource Management and Safety
Bureau of Indian Affairs
via harold.hall@bia.gov

December 21, 2018

Bronwyn Brown, Project Manager
San Diego County PDS
via: Bronwyn.brown@sdcounty.ca.gov

CC elected officials & interested parties

RE: CAMPO WIND EIS SCOPING COMMENTS IN OPPOSITION

Dear Mr. Hall and Ms. Brown,

We hereby incorporate fully by reference the comments submitted in opposition to Campo Wind by the Boulevard Planning Group and Backcountry Against Dumps (BAD) on December 20th, by the Law Offices of Stephan C. Volker on behalf of BAD on December 21st, and by Edith Harmon on December 21st.

INADEQUATE NOTICE OF INTENT, SCOPING NOTICE, AND MEETING – DISRESPECTFUL TO PUBLIC

The Notice of Intent and Scoping Notice were inadequate as has been addressed in the comments referenced above and incorporated into these comments. At the meeting, and prior to, NO project maps were made available to the public, and despite public promises to post a project map and the December 6th presentation at www.campowind.com , those items have not been posted as of mid-afternoon on December 21st, the comment deadline. A copy of the campowind.com website, showing the lack of items posted as of today, has been printed and attached for the record.

During the meeting, speakers were admonished to be respectful when no disrespect was shown. When I tried to speak the court reporter kept telling me to slow down and repeat myself, while I was also being reminded that my allotted and inadequate 3 minutes was rapidly ticking away. It was so bad that my husband, Ed, who was signed up to speak gave me his time.

It is the public and adjacent neighbors who are being disrespected by Terra-Gen, Campo leaders who live miles away on Old Campo, and the bureaucrats who enable them to come in and basically destroy existing residential areas and communities at large, including those on the local reservations.

Terra-Gen's Ken Wagner has been personally notified and made aware of our proximity to their project via email and twice during direct face-to-face contact with me. He has ignored my direct request for him or other project representatives to come to our home to discuss our concerns. When I informed him that we would fight hard, Wagner said they would do the same.

ADJACENT NEIGHBORS- IMPACTS TO 96-YEAR (55 + 41) LIFE-TIME INVESTMENT - REDUCED PROPERTY VALUES-INCREASED FIRE INSURANCE COSTS-POTENTIAL LOSS OF RENTAL INCOME.

These comments are submitted for my family as immediate neighbors of Terra-Gen's proposed Campo Wind project. We strongly object to and oppose the project in its entirety. According to Terra-Gen's attached initial project layout plan map provided by a concerned tribal member—not by Terra-Gen or the BIA, we own 267 acres on two adjacent parcels that share a ½ mile common boundary with the Campo Reservation, BIA 10, and Campo Wind's proposed southeastern boundary.

The photos above and below show our ranch looking west with the Campo Wind site proposed across the entire horizon, north to south (left-right). Several rows of turbines are proposed with the closest around 1,000-1,200 feet from our home and occupied rental property. Currently, our ranch is very quiet with clean uncluttered and calming views in all directions, especially on the west where no transmission lines, lights, or other clutter is present on the sweeping ridge line. We watch the sun set everyday behind that ridge from our living room window or outside.

Our own home , and our old homestead cabin, where our daughter lives, are located on a 120 acre parcel (APN# 658-040-06-00) approximately 1,000 feet or so from BIA 10 and Campo Wind's southeastern boundary. Our rental home is right next door and is located on a 147 acre parcel (658-040-05-00). Luckily, our homes survived the 2012 Shockey Fire that burned through the Campo Wind project site and about 2/3rds of our property. The chaparral and habitat is finally starting to recover.

EXISTING HEALTH ISSUES CAN ONLY BE EXACERBATED BY INDUSTRIAL WIND TURBINES NEXT DOOR.

The comments submitted by the Boulevard Planning Group and BAD cover the basic adverse health and other impacts generated by industrial wind turbines—and Campo Wind is proposing 4MW wind turbines that are twice the size of the 2MW Kumeyaay Wind turbines that have caused so much grief to impacted residents here and elsewhere around the globe.

I have personally communicated with, visited, witnessed, researched and /or physically experienced how impacted the homes and residents are around the Kumeyaay Wind, Tule Wind, Ocotillo Wind, Palm Springs, and other projects in the US, Canada, Australia, and Mexico and know how they suffer while decision makers ignore and mock their very real physical and financial suffering. It is unjust!

It is ludicrous and unconscionable how science and established medical knowledge are continually ignored by those that directly profit, like Terra-Gen and select Campo leadership, and those who wrongly believe that so-called green energy is benign. It is MOT benign! Large turbines equal a form of cruel and unusual punishment and torture. They create both public and private nuisance and loss of use and enjoyment of property and amenities.

Our family, and 6-year rental tenant, who live here, all, has existing health issues that can only be exacerbated by the placement of Terra-Gen's 586 foot tall Campo Wind turbines and other infrastructure. Ed is an 80-year old cancer survivor with a pacemaker. His doctors have warned him to avoid certain electronic exposure to prevent electromagnetic interference. Turbines represent major EMI! I am 66 years old with chronic Lyme disease and co-infections and wonder if the low-frequency noise documented here from existing turbines has prevented my full recovery. Our daughter has a degenerative disease and our rental tenant has undergone about 5 surgeries in the last 2 years. If the Campo Wind turbines are approved and installed and manage to survive litigation, we will all need to move to preserve our already battered health and future well-being. To do that, we will have to sell our beloved ranch property at a huge loss and try to make a new start. We doubt we can replace what we have at an affordable price elsewhere.

TURBINE NOISE ALREADY DOCUMENTED HERE WITH CLOSEST TURBINES OVER 5.6 MILES AWAY

Two professional noise testing sessions have been conducted at our home/ranch and others in 2013 and 2018. Low-frequency noise and infrasound were documented here both times. The professionals identified Kumeyaay Wind and Ocotillo Wind as the sources in 2013. Kumeyaay Wind is about 5.6 miles north of us. Ocotillo Wind is not that far as the crow flies. Tule Wind turbines started operation in late 2017. We have not yet received the finalized report for the 2018 noise documentation.

DOCUMENTED INFRASOUND, LOW-FREQUENCY NOISE & ELECTROMAGNETIC INTERFERENCE (EMI)

I was personally present during the majority of previous testing by Dr. Richard Carman with Wilson Ihrig & Associates (KUMEYAAY AND OCOTILLO WIND TURBINE FACILITIES NOISE MEASUREMENTS 2-24-14) and by Sal La Duca with Environmental Assay, Inc (Manzanita WT report & Appendices A-D dated 2-13) that documented low-frequency noise, infrasound and EMI at impacted homes around the Kumeyaay Wind and Ocotillo Wind turbines. Their reports were provided separately for Backcountry Against Dumps and me via email on December 21st.

<u>Here is a list of the Wilson Ihrig location distance and highest level frequency recorded:</u> D. Elliott 2000 ft 55 dB 1.56 Hz; G. Thompson 2940 ft 58 dB 1.66 H; R. Elliott 4300 ft 55 dB 0.68 Hz; Live Oak Springs

Cabin#2 5890 ft 48 dB 2.54 Hz; Oppenheimer 1.6 miles 45 dB 0.88 Hz; Morgan 1.7 miles 56 dB 1.56 Hz; D. Bonfiglio 2.9 miles 43 dB 1.07 Hz; Tisdale 5.6 miles 43 dB 0.68 Hz

Everyone on the list has complained of adverse impacts including significant sleep, health (including cancer), the use and enjoyment of their homes and property, overall quality of life, and more. Don Bonfiglio informed me recently that he had lost two tenants due to noise from the Kumeyaay Wind turbines and he is almost 3 miles from them. Please note that at about 1,000-1,200 feet, our homes are almost twice as close as the closest of those that were tested previously (D. Elliott 2,000 ft).

Attached is a copy of the July 2015 report: Infrasound Low-Frequency Noise and Industrial Wind Turbines- MULTI-MUNICIPAL WIND TURBINE WORKING GROUP. It is self-explanatory.

SOLE-SOURCE GROUND WATER PROTECTION IS CRITICAL & PAST HISTORY RAISES MAJOR CONCERNS

- **Blasting for turbine foundations can have significant adverse impacts on local well and springs that residents rely on in our highly fractured aquifer. We have worked with professional geologists and others on the former Campo Landfill site that is the current Campo Wind site.**
- There is no alternative source of potable water available unless it is trucked in at great expense.
- Campo tribal leadership previously and unconscionably authorized use of 54 million gallons of Campo Reservation well water drawn from the previously proposed Campo Landfill site for construction of SDG&E's ECO Substation project.
- That original authorization was reportedly done without General Council approval for sale of almost 54 million gallons of tribal assets/ groundwater[1].
- The undated Muht-Hei letter approved the bulk water sales from other wells located at the Campo Materials facility, claiming there was no need for General Council or BIA approval.
- The Muht-Hei letter was approved by Ralph Goff and was included in SDG&E's amended Water Supply Plan sent to the CPUC for the ECO Substation project, dated July 3, 2013[2].
- However, the bulk water sales used Campo wells at the southeastern end of the Campo Reservation on the old Campo Landfill site, nowhere near Campo Materials facility.
- Chairman Ralph Goff had to be aware of the blatant discrepancy because the Environmental Navigational Services, Inc, letter/report (Evaluation of Short-term Construction Water Supply Obtained from the Southeastern Portion of the Campo Indian Reservation., dated June 14,2013[3]) issued to JFI, SDG&E's contractor, clearly states that the source wells in question are located in the southeastern portion of the Reservation, when Campo Materials is located just south of the Golden Acorn Casino, much further north.
- Use of that groundwater resource had to be curtailed early due to on and off-site impacts at wells and springs on tribal lands and adjacent properties and loss of well recovery rates.
- This and other groundwater issues and valid concerns must be taken into consideration prior to any approvals for use of local groundwater for Campo Wind construction and operations.
- Use of recycled water from the City of San Diego would be preferred source.

[1] https://theecoreport.com/campo-general-council-meeting-regard-alleged-unauthorized-water-sales/

[2] See page 79-80 @ http://www.cpuc.ca.gov/environment/info/dudek/ECOSUB/Amended%20Construction%20Water%20Supply%20Plan.pdf

[3] See report at pages 39-80 @ link 27 above.

PLEASE TAKE NOTICE: The self-explanatory email pasted below, requesting information on who owns Kumeyaay Wind and where to file complaints has never been responded to by any of the recipients, including tribal leaders and BIA representatives. Sadly, the lack of any response and concern is what we have come to expect from all of them. We expect no different with Terra-Gen and Campo Wind. That is why we are prepared to fight to prevent another local disaster in the making.

Gmail **Donna Tisdale <tisdale.donna@gmail.com>**

Kumeyaay Wind complaints

Donna Tisdale <tisdale.donna@gmail.com> Mon, Nov 5, 2018 at 9:21 AM
To: info@campo-nsn.gov
Cc: rgoff@campo-nsn.gov, hcuero@campo-nsn.gov, javin.moore@bia.gov, amy.dutschke@bia.gov, dale.risling@bia.gov

Hello,

As the head of the non-profit, Backcountry Against Dumps, both tribal members and non-tribal residents keep complaining to me about Kumeyaay Wind turbines. I don't know where to direct them to get help in resolving their complaints about noise, electromagnetic interference (EMI), flashing lights, and other issues.

Several impacted local tribal members told me they had complained to one or more elected Campo tribal officials who allegedly warned them off by saying they were interfering with Campo's economic development and implied their job might be at risk.

What about the health and safety of those impacted, including children?? Growing research makes it clear that noise, vibrations, infrasound, and EMI, generated by industrial wind turbines, can and does create a nuisance with related adverse impacts to public health and safety, well being, the use and enjoyment of their homes and properties, and property sales and values.

Please provide phone number and email contacts for filing complaints about noise, vibrations, EMI, and leaking oil from the Kumeyaay Wind turbines. Significant leaking oil is clearly evident on turbines near I-8. It indicates poor maintenance and increased noise emissions and fire risk in a CAL FIRE designated Very High Fire Hazard Severity Zone. The previous Kumeyaay Wind turbine fire and flaming debris did spark a small brush fire; luckily it was a day after a Santa Ana wind event and was quickly put out.

The current owner/manager is responsible, but it is unclear who that is. The Muht-Hei link to the wind turbines takes you to EDF Renewables but EDF Renewables does not list the project on their website and is not responding to emails or phone calls about filing complaints or if they still have an ownership stake.

In a few years, the turbines are supposed to be owned outright by the Campo Band. Hopefully, we can get some of these legitimate complaints and turbine maintenance issues resolved before they become a bigger problem, financial burden, and liability for your tribe.

Thank you
Donna Tisdale
619-766-4170

LITIGATION WILL FOLLOW ANY PROJECT APPROVALS TO PROTECT AND DEFEND WHAT WE HAVE

Due to the known and reasonably foreseeable adverse impacts and nuisance that Terra-Gen's Campo Wind project represents to our family, our tenants, and rental income, we will be forced to file suit against any project approvals in order to defend and protect our life-time investment, our health and safety, our finances, the use and enjoyment of our property, our quiet rural ambience, clean air and water, our overall quality of life, pets and wildlife, peaceful, uncluttered, and calming views and more.

- **Attorneys' Fees Can Be Awarded to CEQA Litigants Hoping to Preserve Their Home Values[4], By Lindsey Quock on March 28, 2018**. Posted in CEQA, Environmental and Land Use Litigation: Excerpts- emphasis added:
  - *"Successful petitioners under CEQA who are motivated to file suit, in part, by their private financial interests are not necessarily ineligible for an award of attorneys' fees under the public interest fee statute. Heron Bay Homeowners Association v. City of San Leandro, 19 Cal. App. 5th 376 (2018)."*
  - *"This decision exemplifies the rule that trial courts have considerable discretion in awarding and apportioning attorneys' fees under section 1021.5 based on the particular facts of each case. More importantly, it makes it crystal clear that CEQA plaintiffs that might avoid a decrease in their property values by successfully challenging a project are not cut off from recovering section 1021.5 attorneys' fees*".

INCREASED FIRE RISK AND RELATED INSURANCE COSTS OR CANCELLATION

- Despite industry denials, there *have been* numerous ground/wildfires sparked by flaming wind turbines. It is already hard to find affordable fire insurance out here due to our designation as a Very High Fire Severity Zone. Adding Campo Wind turbines will only make it harder based on the increased fire threat they represent.

- When I tried to track down Terra-Gen's fire / emergency service calls for the turbines they built in Kern County, the fire agency told me they needed physical addresses of those facilities to track down those reports.

- When I asked Terra-Gen's Ken Wager for those physical addresses, he emailed a response that their facilities do not have physical addresses. How convenient.

- **Campo Wind should be required to secure a physical address for reporting and recording all emergency service calls for fire and other events.**

WIND TURBINE NOISE AND WAKE EFFECTS – BIGGER TURBINES = LARGER WAKE EFFECTS AND MORE LOW-FREQUENCY NOISE AND INFRASOUND THAT TRAVELS EVEN FURTHER

- **December 2014: Modelling of low frequency noise from wind turbines Harald Debertshäuser*,Wen Zhong Shen, Wei Jun Zhu, Jens Nørkær Sørensen Technical University of Denmark * hadeb@dtu.dk: [5] (funded by Euro Tech Wind Project) (Excerpt-emphasis added)**

[4] https://www.californialandusedevelopmentlaw.com/2018/03/28/attorneys-fees-can-be-awarded-to-ceqalitigants-hoping-to-preserve-their-home-values/
[5] http://www.ewea.org/events/workshops/wp-content/uploads/2014/11/Tech14b-PO-C006.pdf

- *"The four main causes of low frequency wind turbine noise are: 1. Up-scaling effect Increased wind turbine diameter and airfoil chord length causes a shift to lower frequency noise 2. Inflow turbulence noise Interaction of turbulence with blades causes load fluctuations, which then generates noise 3. Amplitude modulation noise Cyclic load fluctuations due to wind shear, tower, and yaw interaction 4. Wake effects Increased turbulent intensity in the wake causing higher inflow turbulence noise Due to the constant growth of wind turbine diameters over the last decade, predicting low frequency noise will be of great interest for new multi-MW wind turbines. To capture all these effects, a sophisticated numerical simulation method is required."*

- **New research funded by the National Science Foundation and U.S. Department of Energy (DOE)** highlights how upwind turbines can reduce flow to downwind neighbors. It also notes that turbine wakes can extend 50+km downwind. Wakes can also represent one path of low-frequency noise and infrasound and the miles it can travel.

  - **November 26, 2018 Nature.com: New Report: Costs and consequences of wind turbine wake effects arising from uncoordinated wind energy development: J. K. Lundquist, K. K. DuVivier, D. Kaffine & J. Kaffine & J. M. Tomaszewski**[6]

    - *Abstract: Optimal wind farm locations require a strong and reliable wind resource and access to transmission lines. As onshore and offshore wind energy grows, preferred locations become saturated with numerous wind farms. An upwind wind farm generates 'wake effects' (decreases in downwind wind speeds) that undermine a downwind wind farm's power generation and revenues. Here we use a diverse set of analysis tools from the atmospheric science, economic and legal communities to assess costs and consequences of these wake effects, focusing on a West Texas case study. We show that although wake effects vary with atmospheric conditions, they are discernible in monthly power production. In stably stratified atmospheric conditions, wakes can extend 50+ km downwind, resulting in economic losses of several million dollars over six years for our case study. However, our investigation of the legal literature shows no legal guidance for protecting existing wind farms from such significant impacts.*

WILDLIFE IMPACTS

Our property and the general area has a wide array of resident and migratory wildlife with lots of raptors, song birds, mountain lions, bobcats, coyotes, Black-tailed Jack Rabbits, snakes, lizards, toads, butterflies, ground dwellers, and more. Several times my family has witnessed Monarch migration through our ranch and other natural wonders. Quino Checkerspot butterflies have been documented here. The Campo Wind project represents a major threat to the survival and well-being of all of them.

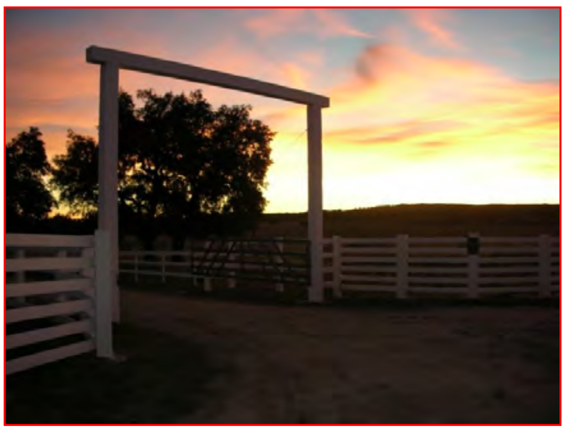
- **Why Birds Matter: AVIAN ECOLOGICAL FUNCTION AND ECOSYSTEM SERVICES EDITED BY ÇAGAN H. SEKERCIOGLU, DANIEL G. WENNY, AND CHRISTOPHER J. WHELAN**[7]

[6] https://doi.org/10.1038/s41560-018-0281-2
[7] https://www.press.uchicago.edu/ucp/books/book/chicago/W/bo23996771.html

- The book provides an overview of birds' ecological functions and ecosystem services, which typically fall into one of four categories:
- Provisioning services, such as game meat for food, down for garments, and guano for fertilizer;
- Regulating services, such as scavenging carcasses and waste, controlling populations of invertebrate and vertebrate pests, pollinating plants, and dispersing seeds;
- Supporting services, such as cycling nutrients, and even contributing to soil formation; and,
- Cultural services, exemplified by birds' prominent roles in art and religion and by the billions of dollars spent on bird watching.

1

PHOTOGRAPHIC EVIDENCE OF WHAT WE HAVE NOW AFTER OVER 96 (55 +41) YEARS OF FAMILY INVESTMENT, BLOOD, SWEAT &TEARS & WHAT WILL BE LOST TO US IF CAMPO WIND IS ALLOWED TO MOVE FORWARD. WE WILL FIGHT TO PROTECT WHAT WE LOVE AND OUR LIFETIME INVESTMENT!

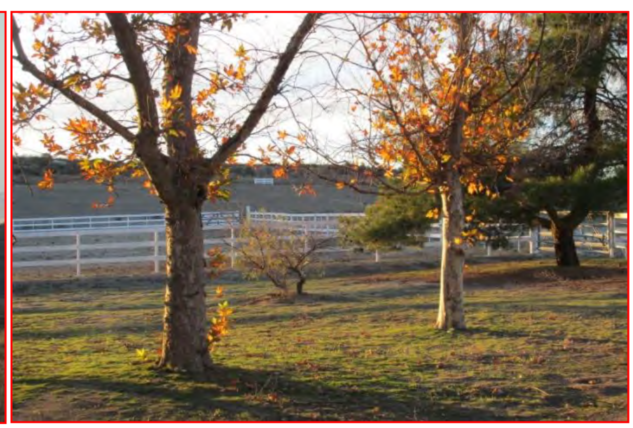



On the left and right: The main entrance to our Morning Star Ranch facing west with the Campo Wind site on the currently uncluttered ridge behind it.


Above left: looking west toward Campo Wind site. On the right: Looking from our main driveway with the Campo Wind site in the right corner.

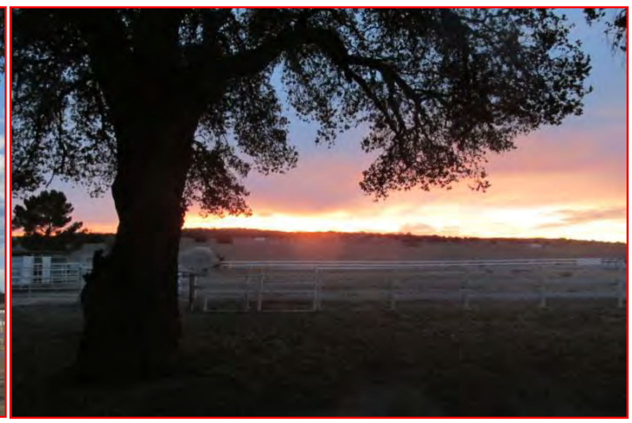
Above left: another view over our ranch to the west with Campo Wind site on the horizon. On the right: Looking southwest with our rental home located in oak grove and the Campo Wind site on the horizon.

Above left: This is what a good windmill looks like as it quietly pumps water for us.
On the right: Our horse, Nelson, with the Campo Wind site on the ridge behind him.



Left above: photo from our property looking west into Campo Valley. Multiple rows of Campo Wind turbines are planned for the entire width of this photo and our entire western, northwestern, and southwestern view sheds. On the right: View of the Campo Wind site through our Sycamore trees by our house.

On the left: photo taken from BIA 10 and Campo Wind site looking east over our property and home with Rattlesnake Mountain in the background. On the right: Looking west over our ranch with Campo Wind site on the first ridgeline with other turbine strings planned to the west.

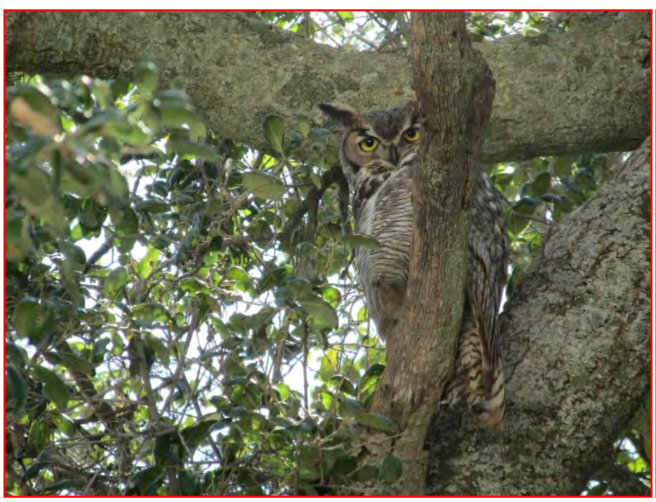


Both photos above were taken from our yard looking northwest and west with the Campo Wind site on the ridge west our home.

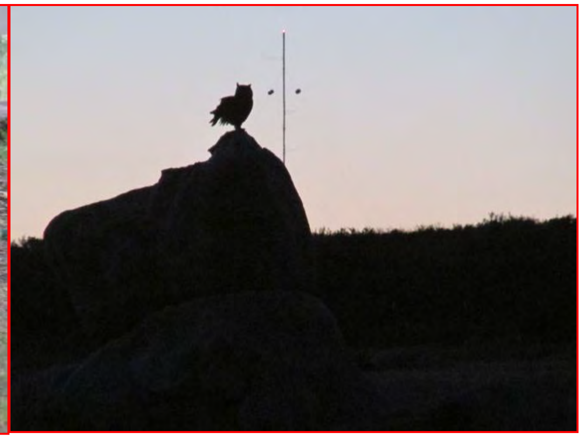
Left above: Our two remaining horses stand in the pasture with the Campo Wind site on the ridge behind them. On the right: cattle grazing in our pasture with the Campo Wind site on the ridge in the background.

On the left: Our horse, Nelson, with the 2012 Shockey Fire burning through the Campo Wind site to the southwest of our house and corrals. On the right: Shockey Fire burning through our property after burning over and sparing our rental house next door.

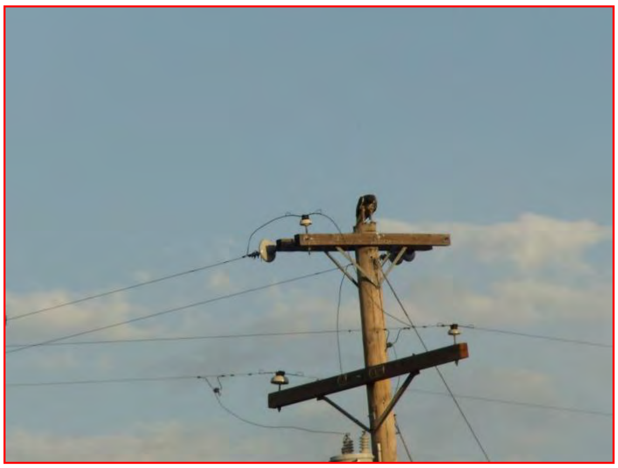
Above: Aftermath of Shockey Fire with the Campo Wind site on the horizon on the left and our rental house on the right.



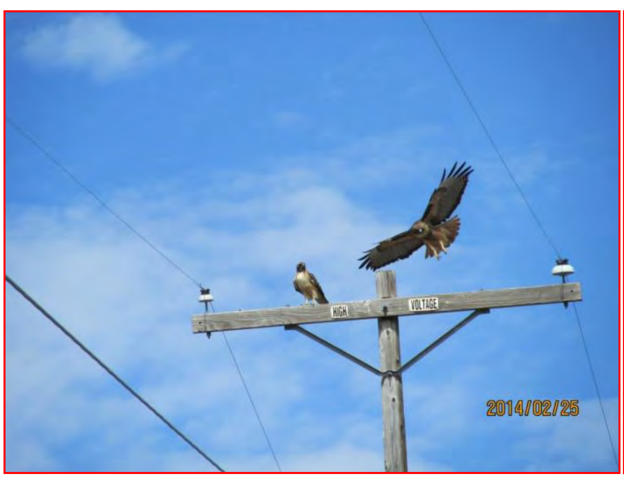
Left above: One of our great horned owls is sitting in an oak in our back yard and one of our resident barn owls rests in our barn on the right.

On the right: one of our owls sits on boulder by our house, with the former Shu'luuk Wind MET tower in the background. Instead of the MET tower, 586 foot tall wind turbines are planned for the same area.

Above: Resident raptors on our utility pole just east of our house and homestead cabin.

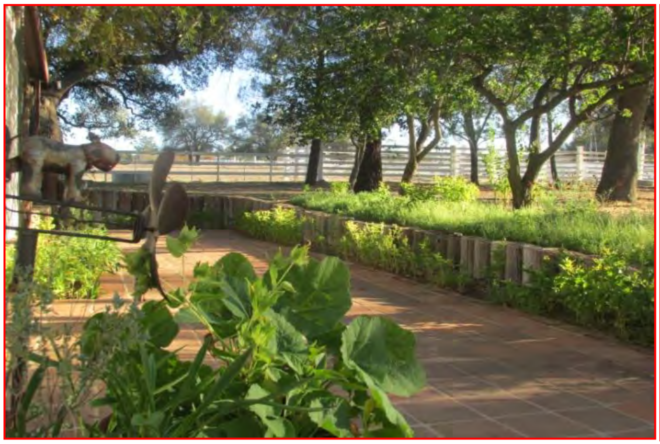


Above left: A pair of Red-tailed Hawks that nest on our ranch. On right: Red-tailed Hawk in flight.

These two hawks were very close to our house. The young one on the left just walked onto our porch and the one on the right was getting a drink.

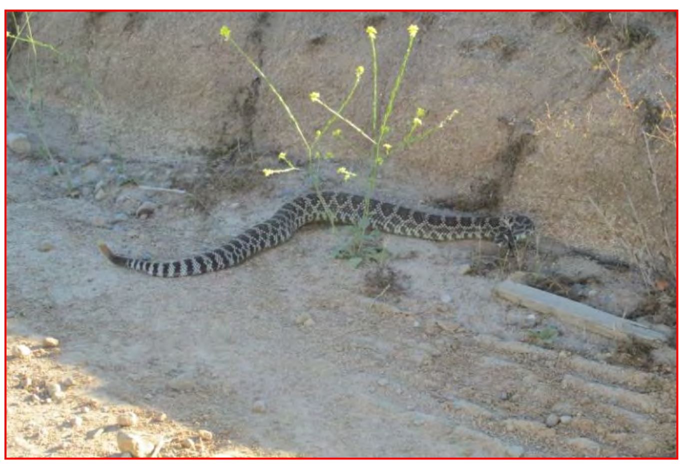
Above left: tri-colored black birds on our telephone wire by our house. On the right: tri-colored blackbirds in our pasture near our house. They migrate through twice a year and are very noisy.

Above left: Lawrence's Goldfinches in a Blue Elderberry tree taken from BIA 10 at our common property line with the Campo Wind project. On the right: California Scrub Jays in a Sugar bush on our property.




Above left: our side flower garden and fruit trees that attract wildlife. On the right: Penstemon flowers blooming on our property.


Above left: Black tailed Jack Rabbits eating our windfall apples; above right: coyote looking for apples and rabbits.



Western Diamond Rattlesnake, one of several varieties here.

PHOTOGRAPHIC EVIDENCE OF WHAT WE DON'T TO WANT TO BE SUBJECTED TO:

Above left: homes impacted by Ocotillo Wind turbines in Imperial County, looking NW from Hwy 98, where noise, low-frequency noise, EMI, increased dust, suspicious foamy runoff, and much more has been documented. See

Above right: A home on Ribbonwood Road, impacted by Kumeyaay Wind turbines that are 1.7 miles away. Noise, low-frequency noise and infrasound were documented there.

Above left: Old wooden home impacted by SDG&E's new 230kV line that connects their ECO Substation to Boulevard Substation. Above right: SDG&E's same 230kV line being constructed through Jacumba, just east of Boulevard.

Above: Gen-tie line for First Solar's Campo Verde Solar project in Imperial County located on previously productive farm land. Campo Wind gen-tie will be equally invasive and obnoxious.

For the record, I personally took all the photos used in this comment letter.

Once again, time restrictions and personal obligations have prevented more in-depth and better edited comments. Any errors or omissions are unintentional. Contact: 619-766-4170; Tisdale.donna@gmail.com

Regards,

Donna Tisdale for the Tisdale Family

<u>3 Attachments</u>:

1. Initial Layout Plan / map for Campo Wind
2. Infrasound Low-Frequency Noise and Industrial Wind Turbines- MULTI-MUNICIPAL WIND TURBINE WORKING GROUP- July 2015
3. Campowind.com printout dated 12-21-18

Campo Wind

Welcome to the website for information regarding the proposed Campo Wind Project

Materials will be posted here for public information as they are generated and in support of decision processes for the project. Please check back frequently. Below are links to documents available in relation to this project at this time.

Notice of Intent to Prepare a Draft Environmental Impact Statement
Notice of Public Scoping Meeting

Infrasound

Low frequency noise

and

Industrial Wind Turbines

An information report prepared for the

MULTI-MUNICIPAL WIND TURBINE WORKING GROUP

MARK DAVIS, DEPUTY MAYOR, ARRAN-ELDERSLIE, CHAIR / STEWART HALLIDAY, DEPUTY MAYOR, GREY HIGHLANDS, CO-CHAIR

1925 BRUCE ROAD 10, BOX 70, CHESLEY, ON NOG 1L0 / 519-363-3039 / FAX: 519-363-2203 areld@bmts.com

Compiled by

Keith Stelling, MA, (McMaster) MNIMH, MCPP (England)

Reviewed by

William K. Palmer, P. Eng.

Carmen Krogh, BSc (Pharm), provided comments on the health component

July, 2015

Contents

Introduction

The Multi-municipal Wind Turbine Working Group was formed by municipal councillors in Grey, Bruce, and Huron Counties in Ontario in response to the growing number of complaints they were receiving from constituents concerning the installation of industrial wind turbines throughout the area. Councillors were aware of their responsibility regarding the health, safety, and well-being of their constituents. The Multi-municipal Wind Turbine Working Group was set up to share ideas on how to fulfill that responsibility. Complaints from citizens, including reports of adverse health impacts have persisted and increased as more turbines have been installed. The reported symptoms conform to those described internationally by many people living near wind turbines.

With the proliferation of recent research and the rediscovery of earlier, until now largely ignored studies, infrasound and low frequency noise (LFN) can no longer be dismissed as irrelevant. This report shows why it must be given full consideration as a contributing cause of the distress of some of those people living near wind turbine installations. It also demonstrates why the Ontario and Canadian governments must pay attention to this research, fulfill their obligation to protect the health of our citizens and amend their wind turbine regulations and policies.

Executive summary

Typically, regulating authorities have not required the measurement of infrasound (sound below 20 Hz in frequency) and low frequency (LFN) (generally sound from 200

Hz to 20 Hz) inside homes adjacent to wind turbines as a condition of their installation and operational monitoring.[1] The health risk of infrasound from wind turbines has been dismissed by the wind industry as insignificant. It has maintained that since the typical loudness and frequency of wind turbine sound within a home is not audible, it cannot have any effect on human health.

Noise measurements for most studies and environmental assessments have been limited to the measurement of *audible* sound *outside* homes-- using dBA weighted monitoring which is insensitive to infrasound frequencies. Some studies and environmental assessments have even relied on *projected* audible sound averages from computer produced models.

Such observations and projections fail to take appropriate account of the distinguishing signature of the sound from a wind turbine. Unlike the more random naturally occurring sounds (such as wind or lake waves which may themselves have an infrasound component), the sound from wind turbines displays characteristics that produce a *pattern* that the ear and audio processing in the brain recognize. Our hearing is strongly influenced by pattern recognition. (This is why we can pick out the sound of a familiar voice even in a crowded room with many people speaking).

One recognizable wind turbine pattern is a tonal signal of *sharply rising and falling pulses* in the infrasound range, (typically about 0.75 Hz, 1.5 Hz, 2.25 Hz, 3.0 Hz, and so on). It is produced by the blade passing the tower. At this frequency these pulses may be “felt or sensed” more than “heard” by the ears. Research by Dr. Alec Salt and others has demonstrated that subaudible infrasound does result in a physiological response from various systems within the body.

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[1] Denmark does require a calculation of the *expected* infrasound; however it is less restrictive than limits on *audible* sound.

The second recognizable pattern is the amplitude modulation. This is the typical "swoosh" rising and falling that *is* audible. [2]

A third recognizable pattern of sound from wind turbines results from the equipment in the nacelle (such as the gearbox if the turbine has one) and ventilating fans. Although in some cases this third sound source may become predominant, it is usually of lesser effect that the first two.

We now know that *subaudible pulsating infrasound can be detected inside homes* near operating wind turbines. It can also be identified up to 10 kilometres distant. We know also that *very low levels of infrasound and LFN are registered by the nervous system and affect the body even though they cannot be heard.* The research cited in this report implicates these infrasonic pulsations as the cause of some of the most commonly reported "sensations" experienced by many people living close to wind turbines including chronic sleep disturbance, dizziness, tinnitus, heart palpitations, vibrations and pressure sensations in the head and chest etc.

Similarly, there is medical research (also cited below) which demonstrates that pulsating infrasound can be a direct cause of sleep disturbance. In clinical medicine, chronic sleep interruption and deprivation is acknowledged as a trigger of serious health problems.

[2] It results from the blade passage frequency which acts to cause the broadband sound produced by the turbulence associated with the airfoil of the wind turbine passing through the air to rise and fall.

I. The work of Neil Kelley

1979: First report of human distress from wind turbines

The first wind turbine noise complaints in North America, reported over 35 years ago, sound strikingly familiar today. Residents living within 3 kilometres of a 2 MW wind turbine near Boone, North Carolina, described a periodic "thumping" sound accompanied by vibrations. Many said that they could "feel" more than hear the sounds. They spoke of repetitive sleep disturbance and maintained that the sounds were louder and more annoying inside their homes than outside; some became more sensitive to the impact over time.

The overlooked documents on wind turbine infrasound

In response to the complaints from Boone, the U.S. Department of Energy and the National Aeronautics and Space Administration (NASA) commissioned Dr. Neil Kelley and his colleagues at the Solar Research Institute (which later became the National Renewable Energy Laboratories of the US Department of Energy) to investigate possible causes. Over the next ten years, Kelley was able to take advantage of government and NASA facilities and funding to carry out extensive field investigations and laboratory research of a scope and thoroughness that has not been matched since. He also had access to experts at six leading American Universities as well as the co-operation and input of the wind turbine industry.[3]

[3] In cooperation with NASA, the General Electric Company, and BREMC, Kelley and his associates at the Solar Energy Research Institute (SERI) performed a series of field measurements near the MOD-1 [turbine] during five separate sessions between 1979 and 1981. They were supported by the Pacific Northwest Laboratories and the University of Virginia, Department of Environmental Science. In addition to the measurement programs, SERI conducted ancillary experimental studies at the NASA Plumbrook Facility; the DOE Rocky Flats Wind Energy Research Center; the anechoic wind tunnel of MIT's Department of Aeronautics and Astronautics; and the subsonic wind tunnel facilities of the Department of Aerospace Engineering of the University of Colorado-Boulder (UCB). Analytical and field studies of low-frequency noise propagation in the vicinity of the turbine were conducted by a

Between 1982 and 1988, Kelley and his colleagues published five important papers:

1. N. D. Kelley, R. R. Hemphill, M. E. McKenna. **"A Methodology for Assessment of Wind Turbine Noise Generation", 1982**. (First published in J. *Solar Engineering,* Vol. 21 (1981), pp.341-356).

2. E. W. Jacobs, N. D. Kelley, H. E. McKenna, N. J. Birkenheuer. **"Wake Characteristics of the MOD-2 Wind Turbine at Medicine Bow, Wyoming". November 1984.**

3. N. D. Kelley, H. E. McKenna, R. R. Hemphill, C. l. Etter, R. l. Garrelts, N. C. Linn. **"Acoustic Noise Associated with the MOD-1 Wind Turbine: Its Source, Impact, and Control". February 1985**. (First published by the Solar Energy Research Institute, February 1985). **(262 pages)**

4. N.D. Kelley. **"A Proposed Metric for Assessing the Potential of Community Annoyance from Wind Turbine Low-Frequency Noise Emissions", November 1987.**

5. N. D. Kelley, H. E. McKenna, E. W. Jacobs, R. R. Hemphill, J. Birkenheuer. **"The MOD-2 Wind Turbine: Aeroacoustical Noise Sources, Emissions, and Potential Impact"**. Solar Energy Research Institute. Prepared for the U.S. Department of Energy, **January 1988.**

His work was published in peer reviewed journals. He presented his paper "Acoustic Noise Associated with the MOD-1 Wind Turbine: Its Source, Impact, and Control" at the Fourth ASME (American Society of Mechanical Engineers) Wind Energy Symposium held in Dallas, Texas on 18-20 February 1985. In 1987 he presented his paper "A Proposed Metric for Assessing the Potential of Community Annoyance from Wind Turbine Low-Frequency Noise Emissions", at the American Wind Energy Association "Windpower '87 Conference and Exposition", October 5-8, 1987 in San Francisco, California.

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multidisciplinary group at Penn State; and analytical studies of aerodynamic noise generation were performed by the Fluid Dynamics Research Laboratory of MIT's Department of Aeronautics and Astronautics. In addition a number of other organizations were active in the noise investigations: NASA Lewis Research Center--analytical modeling of noise generation by wind turbines; NASA Langley Research Center- aeroacoustical and psychophysical studies of wind turbine noise; General Electric Company Corporate Research Center--analytical and statistical studies of the MOD-l noise situation and wind turbine noise in general; Boeing Vertol Division--wind turbine aeroacoustic studies; Hamilton-Standard Corporation--analytical studies of wind turbine aeroacoustics; the Fluid Dynamics Research Laboratory of MIT's Department of Aeronautics and Astronautics and the Departments of Meteorology and Mechanical Engineering; and the Noise Control Laboratory at Penn State were retained under SERI subcontracts to develop analytical techniques for evaluating the physics of the sound generation process and the propagation aspects of the problem, respectively.

The NASA investigation by Dr. Neil Kelley and his colleagues *established a link between wind turbine generated impulsive infrasound and low frequency noise and the symptoms (including sleep disturbance)* reported by the Boone, North Carolina residents.

The first report was based on three years of detailed field research. It recorded the experiences of actual people living near turbines through their resident diaries. It involved a complete set of full spectrum acoustic measurements (not estimated computer projections limited to A-weighted sound) extended over the entire 3 year study period. It included sound and vibration measurements as well as detailed meteorological observations.

It was followed by the publication of the results of subsequent laboratory research. Human volunteers were directly exposed in the laboratory to some of the sound energy in the infrasound and low frequency noise frequencies similar to the wind turbine measurements. The individual human responses confirmed an association between infrasound/LFN and the distress experienced by the volunteers.

Kelley's key findings

(1) Wind turbines emit infrasound.

- "The modern wind turbine radiates its peak sound power (energy) in the very low frequency[4] (VLF) range, typically between 1 and 10 Hz."[5]

[4] The audible spectrum of sound for adults is generally considered to range from 20 Hz to 20,000 Hz. Frequencies below 20 Hz are described as *infrasound.* The range from 20 Hz to 200 Hz is usually described as low frequency sound.

[5] N.D. Kelley. "A Proposed Metric for Assessing the Potential of Community Annoyance from Wind Turbine Low-Frequency Noise Emissions", November 1987, p.1.

(2) Wind turbine infrasound and low frequency noise is often subaudible.

- "The detailed analysis of a series of acoustic measurements taken near several large wind turbines (100 kW and above) has identified the maximum acoustic energy as being concentrated in the low-frequency audible and subaudible ranges, usually less than 100 Hz".[6]

(3) Wind turbine infrasound and LFN is characteristically impulsive (pulsating, containing spikes or peaks and valleys).

- "Impulsive noise, such as has been found with the MOD-1, is identified with short, transient fluctuations in the radiated acoustic field which can contain considerable energy".[7]

(4) Community annoyance described by residents

- "Residents living in affected houses reported periodic "thumping" sounds accompanied by vibrations".
- Many said that they could "feel" more than hear the sounds.
- They spoke of repetitive sleep disturbance.
- "These field measurements and model results allowed us to conclude the following: The annoyance was real and not imagined". [8]

(5) Community annoyance is related to impulsiveness

- "These measurements have also shown any reported community annoyance associated with turbine operations has often been related to the degree of coherent impulsiveness present and the subsequent harmonic coupling of acoustic energy to residential structures".[9]

[6] N. D. Kelley, R. R. Hemphill, M. E. McKenna. "A Methodology for Assessment of Wind Turbine Noise Generation", 1982, p.1.
[7] *Ibid.*, p.113.
[8] Kelley *et al.* 1985 p. iii.
[9] Kelley *et al*., 1982, *op. cit.* p.112.

(6) Wind turbine disturbance is detected more *inside* houses than outside.

- "Residents reported the sounds were louder and more annoying inside their homes than outside".
- "Experience with wind turbines has shown that it is possible, under the right circumstances, for low-frequency (LF) acoustic noise radiated from the turbine rotor to interact with residential structures of nearby communities and annoy the occupants". [10]

- "An extensive investigation . . . revealed that this annoyance was the result of a coupling of the turbine's impulsive LF acoustic energy into the structures of some of the surrounding homes. This often created an annoyance environment that was frequently confined to within the home itself".[11]

- "The strong resonant behavior of the indoor pressure field when excited by an external impulsive excitation, all point to a complex resonance condition between the volume of air in the rooms and the vibration (displacement) of the walls and floors surrounding it".[12]

- "We found that the periodic loading by the MOD-1 [wind turbine]impulses excited a range of structural resonances within the homes measured". [13]

(7) Sound measurements and residents' reactions (diarized) were compared

- "These results, limited as they are, seem to confirm that people do indeed react to a low frequency noise environment and A-weighted measurements are not an adequate indicator of annoyance when low frequencies are dominant". [14]

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[10] *Ibid. p. 112.*
[11] Kelley, 1987, p.1.
[12] Kelley *et al*, 1982*,* p. 116. Kelley also cites Hubbard, H, & Shepherd, K. "The Helmholtz Resonance Behavior of Single and Multiple Rooms". NASA/CR-178173, Hampton, VA: NASA Langley Research Center (September 1986).
[13] Kelley, 1987, p. 1.
[14] Kelley, 1987, p.6.

(8) A structural pattern differentiates turbine emissions from background noise

- "The acoustic pressure patterns radiated from large wind turbines have a definite structure as compared with the natural, wind-induced background".[15] [IWT emissions are different from background noise.]
- "The acoustic pressure patterns radiated from large wind turbines have a definite structure as compared with the natural, wind-induced background". [16]

(9) Human body resonances associated with annoyance

- "We hypothesize one of the causal factors related to the annoyance associated with the pulsating pressure fields in the rooms measured is a coupling with human body resonances which in turn are responsible for creating the sensation of a whole-body vibration. This perception is more noticeable indoors due to the increased reverberation time and dynamic overpressures from the interaction between the structural and air volume resonances. [17]

- "There is evidence that the strong resonances found in the acoustic pressure field within rooms actually measured indicates a coupling of subaudible energy to human body resonances at 5, 12, and 17-25 Hz, resulting in a sensation of whole-body vibration".[18]

(11) A-weighted measurements inadequately indicate low frequency annoyance

- "A-weighted measurements are not an adequate indicator of annoyance when low frequencies are dominant".[19]

[15] *Ibid*.
[16] *Ibid*. p. 119.
[17] "From the meager information available from our measurements, we have crudely estimated the perception levels for the body resonance frequencies as 60 dB for 5 Hz, 55 dB for 12 Hz, and 48 dB for the 17-25 Hz band, or +5, 0, and + 10 dB above the existing background for the respective frequencies. Such a process as proposed would explain the perceived annoyance within homes when no perceptable sounds could be heard outdoors". *Ibid.,* p. 119.
[18] *Ibid.* p. 120. See also "Vibrations of 0.5 Hz to 80 Hz have significant effects on the human body", p. 17.
[19] Kelley, 1987, p.6.

Industry denies wind turbine infrasound emissions

For nearly three decades Kelley's work has been overlooked or intentionally sidestepped. The industry has continued to deny that wind turbines emit infrasound or that it affects nearby residents. In 2009 Robert Hornung of CanWEA misadvised the Ontario Ministry of the Environment:

> "No peer-reviewed study has ever established a link between infrasound from turbines and human health. . .".[20]

In responding to the recent re-discovery of Kelley's research by the public, Australian Clean Energy Council policy director Russell Marsh said the study was not relevant to modern turbines. "This is the equivalent of taking a study about Ataris and applying it to the latest iPads," Mr. Marsh said.

However, the latest much larger wind turbines have been found to emit even more infrasound.

In 2011, Henrik Møller and Christian Pedersen of Aalborg University, Denmark, pointed out that as turbines increase in size, the relative amount of low-frequency noise is greater.

> "It is thus beyond any doubt that the low-frequency part of the spectrum plays an important role in the noise at the neighbors. . . . It must be anticipated that the problems with low-frequency noise will increase with even larger turbines."[21]

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[20] Letter from Robert Hornung, Canwea to Marcia Wallace, Ministry of the Environment dated July 24, 2009.

[21] "The relative amount of low-frequency noise is higher for large turbines (2.3–3.6 MW) than for small turbines (below 2 MW), and the difference is statistically significant." Moller, H., Pedersen, C.F., "Low-frequency noise from large wind turbines". J. Acoust. Soc. Am. 129 (6), June 2011.

In 2013, acoustician Richard James noted

> ". . . the shifting of the acoustic energy to lower frequencies that has occurred as wind turbines have increased in size from the 1.5 MW models common in 2008 to the 2.5 MW and higher models currently being installed".[22]

He added:

> "Studies by Dr. Neil Kelley demonstrated that low levels of pulsating tonal infrasound caused adverse reactions in test subjects. This research is generally denied by the wind industry and its acoustical experts. In a recent interview, Dr. Kelley now retired from a managerial position at the National Renewable Energy Laboratory (NREL), re-confirmed that the studies he conducted in the 1980's apply to the modern upwind wind turbine designs in use today. He challenged acousticians to install infrasound measurement instruments inside homes if they doubted his opinion".[23]

In the United Kingdom, *"ETSU-R-97"*, a noise guideline document put together in 1997 by the wind industry "noise working group", excludes any reference to the NASA research or to low-frequency noise. It relies exclusively on the dB(A) weighting (found to be irrelevant ten years earlier as a consequence of the NASA research). It assumes that, in all cases, the sound pressure levels inside neighbouring homes are substantially less than what is recorded outside those homes and it neglected the NASA research which showed that inside a house annoyance might be increased when low frequencies are dominant. It excludes testing inside homes for noise of any

[22] James, Richard R. "Opening Statement at hearing re: BluEarth Project, Bull Creek, Alberta". Proceeding Number 1955, 18th November, 2013.
[23] James, R. "Wind Turbine Infra and Low-Frequency Sound: Warning Signs That Were Not Heard". 2012. Bulletin of Science, Technology & Society 32(2) 108–127. DOI: 10.1177/0270467611421845.

frequency.[24] Ontario wind turbine regulations require only dB(A) measurements and do not require LFN or infrasound measurements or noise monitoring inside homes.

The wind industry has opposed all attempts to change standards to include the measurement of low-frequency noise and infrasound or to set controls for low-frequency noise and infrasound inside homes. It has rejected requirements for turbine operators to cooperate in meaningful noise testing by shutting turbines on and off in order to distinguish between the noise generated by turbines and environmental noise. It has refused to provide operational data, such as wind speed and power output data. Instead it has lobbied for higher noise limits to permit larger turbines.

The industry is still determined to keep infrasound measurements out of REA approvals by lobbying environment ministries:

> "CanWEA takes issue with the requirement for infrasound monitoring. . ."
> "Studies across the world have shown that turbines do not produce infrasound at levels anywhere near those that can have an impact on humans. . . . CanWEA submits that the proposed requirement for infrasound or low frequency noise monitoring as a condition of the REA be removed". [25]

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[24] ETSU-R-97 also establishes methods which allow for the placement of monitoring equipment in locations where high background levels can be recorded prior to construction and subsequently, noise level criteria can be met by simply shifting the location of the monitoring equipment into the open away from trees or bushes—lowering the background levels to allow for wind turbine noise.

[25] CanWEA EBR Posting 010-6516 (Proposed Ministry of the Environment Regulations to Implement the Green Energy and Green Economy Act. 2009) – CanWEA's Supplemental Submission dated July 24, 2009, EBR Comment ID 123788. Signed Robert Hornung President.

Similarly in 2012, the multi-national Denmark-based wind turbine manufacturer, Vestas lobbied the Australian government proposing the removal of the requirement to measure low frequency noise from the Draft Guidelines:

> "Analysis of wind turbine spectra shows that low frequency noise is typically not a significant feature of modern wind turbine noise and is generally less than that of other industrial and environmental sources."
> "It is therefore unnecessary to require the prediction and monitoring of low frequency noise emissions from wind turbines".[26]

II. Recent verification of Kelley's work

A test of good science is the ability to repeat the experiment and obtain the same results. In recent years, a number of researchers have carried out studies that relied on full spectrum noise measurements instead of simple A-weighted ones. They have also recognized the importance of placing monitoring equipment *inside* homes rather than only outside. They have identified the pulsating feature of infrasound from wind turbines as a characteristic that allows it to be distinguished from the naturally occurring background infrasound. They have been able to measure infrasound output from turbines and relate it to symptoms experienced by some people living nearby. The harmful effect of wind turbine infrasound on human health—especially its potential to disturb sleep in some individuals—has been investigated; similarly, the negative effect on human health from sleep deprivation has been well documented. The following sections summarize these findings and review three preliminary studies carried out between 2011 and 2015 which validate Dr. Kelley's work. They are followed by a survey of medical research on the adverse effects of infrasound.

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[26] Vestas Australian Wind Technology PTY Ltd, letter to New South Wales NSW Department of Planning and Infrastructure dated 14 March 2012.

Malcolm Swinbanks 2012

Swinbanks demonstrated the perception of infrasound at significantly lower levels than has hitherto been acknowledged.

- "Conventional assessments of the perception of infrasound based on mean (rms derived) sound energy levels underestimate the importance of the associated crest factor of very low frequency sound pressure variations".

The results of simulations were compared to independently reported effects which have been observed in laboratory testing by other researchers. [27]

Richard James 2012

In 2012, Richard James published a short article entitled "Wind Turbine Infra and Low-Frequency Sound: Warning Signs That Were Not Heard".[28]

- "There is sufficient research and history to link the sensitivity of some people to inaudible amplitude-modulated infra and low-frequency noise to the type of symptoms described by those living near industrial wind turbines".

- "This information should have served as a warning sign. Experts, some well known in the field of acoustics, have defended the wind industry position through white papers, reports, and

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[27] Swinbanks, M. "The Audibility of Low Frequency Wind Turbine Noise". *Fourth International Meeting on Wind Turbine Noise*, Rome Italy, 12-14 April 2011 Inter.Noise USA, 2012.
[28] James R. *Op cit.*

testimony in hearings, and through committees that are establishing guidelines for siting industrial-scale wind turbines.

- “The acoustics profession and individual acousticians should have recognized the early reports of symptoms by people living near wind turbines as a new example of an old problem. Instead of advocating caution in locating wind turbines near people, the rush for renewable energy took precedence. The position or belief that there was little or no possibility inaudible infrasound and very low–frequency noise could be causing the reported problems has delayed further research and the safe implementation of industrial wind turbines.

- “It is the author’s opinion that had past experience and information, which was available prior to the widespread implementation of the modern upwind industrial-scale wind turbine, been incorporated into the government and industry guidelines and regulations used to siting wind turbine utilities, many of the complaints and AHEs (adverse health effects) currently reported would have been avoided”.[29]

In a newspaper interview he stated:

- “Instead, they have large spikes of (peaks or crests) that are as much as 100 to 1,000 times higher in pressure than the pressure in the valleys between the spikes,” said James. “While the average sound pressure level of the tones may not appear to be very significant, it is the peaks of the pressure waves that are significant. . . . Information of this type shows that modern upwind industrial-scale wind turbines can produce significant levels of infrasound and that the sounds produced are a complex mix of tones with rapid modulation patterns. These sounds will likely be more easily perceived than steady pure tones in a laboratory. The potential for dynamically modulated infra and low-frequency sounds to cause AHEs (adverse health effects) has been known for other types of noise sources. There is sufficient infrasound and very low–

[29] *Ibid.,* p. 125.

> frequency noise produced by modern wind turbines to warrant caution when locating turbines in communities proximate to residential properties based on the potential for AHEs." [30]

III. Three preliminary studies replicating Kelley's findings

1. The Falmouth Study, December 2011

This investigation is also known as the "Bruce McPherson Infrasound & Low Frequency Noise Study" in honour of the philanthropist who created the private grant "to determine why there were so many strong complaints about the loss of well-being and hardships experienced by people living near large industrial wind turbines operating in Falmouth, Massachusetts".

The chief investigators, Stephen Ambrose and Robert Rand, set out to confirm or deny the presence of infrasonic and low frequency noise emissions (ILFN) from the "WIND 1", a municipally-owned Vestas V82 industrial wind turbine.

However to the surprise of the acousticians, almost immediately upon entering the study area, they themselves succumbed to the same adverse health symptoms that had been described by the people living near large industrial wind turbine sites in the area.

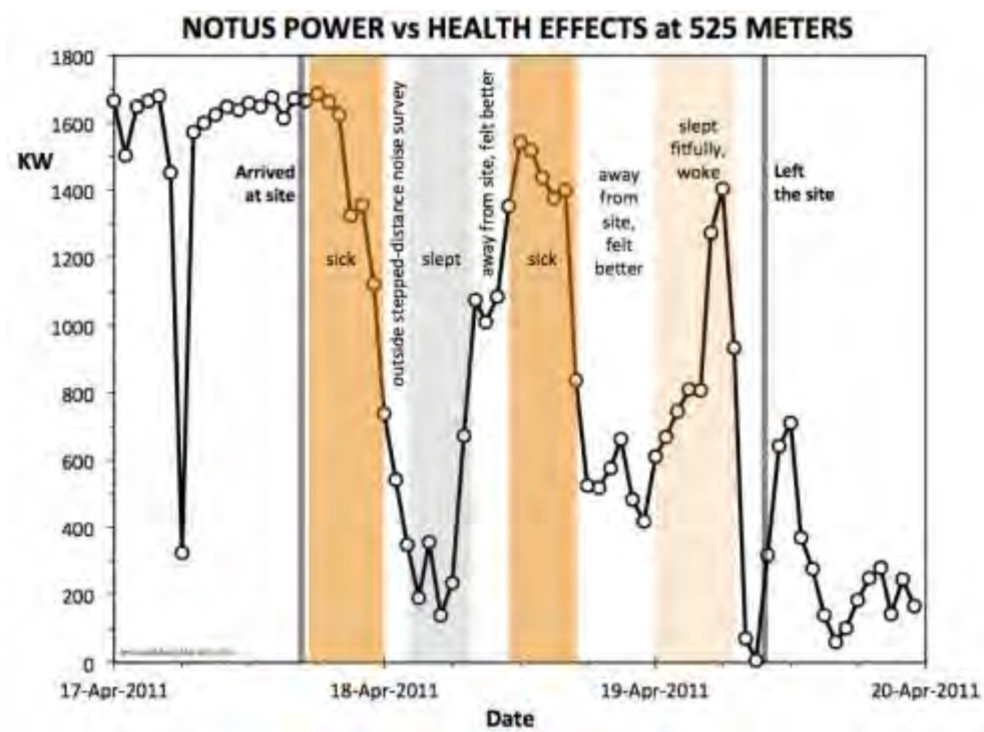
> "The onset of adverse health effects was swift, within twenty minutes, and persisted for some time after leaving the study area. The dBA and dBC levels and modulations did not correlate to the health effects experienced. However, the strength and modulation of the un-weighted and dBG-weighted levels increased indoors consistent with worsened health effects experienced indoors**.** The dBG weighted level appeared to be controlled by in-flow turbulence and exceeded

[30] Rick James. Quoted in *Times News*, Glencoe, Pa, Nov. 17, 2014.

physiological thresholds for response to low-frequency and infrasonic acoustic energy as theorized by Salt".[31]

It took the investigators about a week to recover from the adverse health effects experienced during the study, with lingering recurring nausea and vertigo for almost seven weeks for one of them.

The graph below presents the daily time-history variations in IWT output, observations and physiological symptoms experienced. There is a strong correlation between IWT power output and physiological symptoms. [32]



[31] Ambrose, S, & Rand, R. "The Bruce McPherson Infrasound and Low Frequency Noise Study Adverse Health Effects Produced By Large Industrial Wind Turbines Confirmed", 2011, p.2.
[32] Ambrose, S, Rand, R, Krogh, C. "Falmouth, Massachusetts wind turbine infrasound and low frequency noise measurements", Proceedings of *Inter-Noise 2012*, New York, NY, August 19-22, 2012.

Interestingly, when Ambrose and Rand conducted the Bruce McPherson Study, they were as yet unaware of Kelley's work at the DOE.[33]

The study confirmed Kelley's observation that the LFN causing health problems was inaudible;[34] that sleep disturbance resulted from it;[35] and that infrasound was measured inside the house. The study also affirmed Dr. Kelley's hypothesis of subsequent harmonic coupling of acoustic energy to residential structures.[36] It also re-iterated Kelley's observation that low frequency noise from wind turbines is impulsive:

> "The house envelope blocked most of the frequency content above 10 Hz, and amplified the remaining low frequency pulsations, much like a drum. The acoustic pressure swung from positive (compressed) to negative (rarified) 0.2 Pa peak-to-peak. . . . This increase in modulation indoors was consistent with the stronger adverse health effects Indoors" [37]

> "Our instrumentation reported the Crest Factor at 11-12 dB outdoors and indoors. This suggests that the RMS measurements reported on our graphs are well below the peak levels detectable by the human ear".[38]

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[33] Robert Rand. Personal communication (email) 8 July, 2015.

[34] "The wind turbine tone at 22.9 Hz was not audible yet the modulated amplitudes regularly exceeded vestibular detection thresholds". (Ambrose *et al*., 2011, p.3)

[35] "Sleep was disturbed during the study when the wind turbine operated with hub height wind speeds above 10 m/s". (*Ibid.*)

[36] "The coherence values indicate that the very-low-frequency energy found below 10 Hz was very strongly coupled into the house interior, consistent with the indoors pressure amplification". *(Ibid., p.40)*

"The 'Indoors' graph shows the house envelope filtered and amplified very low frequency content of the wind turbine sound. What is apparent is that the negative pressure swings (vacuum) are more pronounced indoors compared to outdoors". (*Ibid.)*

[37] *Ibid.,* p. 42.

[38] *Ibid.,* p. 43.

The observation that sensitization occurs as exposure continues may be explained in the fact that

> "It is generally accepted that human response and cumulative effects increase with the quantity and the peak level of intrusive noises. Peak noise events are additive".[39]

Ambrose and Rand emphasized that "the infrasonic and low-frequency pulsations are hidden by the A-weighting filtering normally used by noise consultants to assess noise levels; yet, these pulsations are clearly visible in the linear, un-weighted time history in Pascal". [Pascal is the unit for sound pressure (Pa)][40]

> "The research is more than just suggestive. Our experiencing of the adverse health effects reported by others confirms that industrial wind turbines can produce real discomfort and adverse health impacts. Further research could confirm that these ill effects are caused by pressure pulsations exceeding vestibular thresholds, unrelated to the audible frequency spectrum but are instead related to the response of the vestibular system to the low frequency noise emissions. The vestibular system appears to be stimulated by responding to these pressure pulsations rather than by motion or disease, especially at low ambient sound levels.
>
> "The acoustic energy from the wind turbine was found to be: 1) Greater than or uniquely distinguishable from the ambient background levels, and 2) Capable of exceeding human detection thresholds". [41]

The investigators concluded:

[39] *Ibid.,* p. 45.
[40] *Ibid.,* p. 43.
[41] *Ibid.,* p. 3.

> “This research revealed that persons without a pre-existing sleep deprivation condition, not tied to the location nor invested in the property, can experience within a few minutes the same debilitating health effects described and testified to by neighbors living near the wind turbines. The debilitating health effects were judged to be visceral (proceeding from instinct, not intellect) and related to as yet unidentified discordant physical inputs or stimulation to the vestibular system. Health effects moderated when dBG levels fell well below the 60 dBG guideline when the wind turbine was OFF”.[42]

2. Shirley, Brown County, Wisconsin, 2012

The investigation of the Shirley wind project was carried out co-operatively by four different acoustic firms. They concluded:

> “The four investigating firms are of the opinion that enough evidence and hypotheses have been given herein to classify LFN and infrasound as a serious issue, possibly affecting the future of the industry. It should be addressed beyond the present practice of showing that wind turbine levels are magnitudes below the threshold of hearing at low frequencies”[43]

> “This cooperative effort has made a good start in quantifying low frequency and infrasound from wind turbines. Unequivocal measurements at the closest residence R2 [Residence 2] are detailed . . . showing that wind turbine noise is present outside and inside the residence. Any mechanical device has a unique frequency spectrum, and a wind turbine is simply a very large fan and the blade passing frequency is easily calculated by RPM/60 x the number of blades, and for this case; 14 RPM/60 x 3 = 0.7 Hz. The next six harmonics are 1.4, 2.1, 2.8, 3.5, 4.2 & 4.9

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[42] *Ibid.,* pp. 46-47.

[43] Walker, B., Hessler, G., Hessler, D, Rand, R. & Schomer, P. “A Cooperative Measurement Survey and Analysis of Low Frequency and Infrasound at the Shirley Wind Farm in Brown County, Wisconsin”. Report Number 122412-1 Issued: December 24, 2012, p. 167.

> Hz and are clearly evident . . . . Note also there is higher infrasound and LFN inside the residence in the range of 15 to 30 Hz that is attributable to the natural flexibility of typical home construction walls.[44]

Robert Rand reported ill effects (headache and/or nausea while testing and severe effects for 3+ days after testing.

Dr. Paul Schomer was one of the investigating acousticians on the Shirley project. In his report which was attached as Appendix D to the main Wisconsin report, he outlined the implications of the measurements of the Shirley Wind Farm:

- "At most locations where these health problems occurred, the wind turbines were generally not audible. That is, these health problems are devoid of noise problems and concomitant noise annoyance issues".

- "Residents of the nearest house reported that their baby son, now 2 years old, would wake up 4 times a night screaming. This totally stopped upon their leaving the vicinity of the wind turbines, and he now sleeps 8 hours and awakens happy. The fact that these residents largely report wind turbines as inaudible, and the reported effects on a baby seem to rule out the illness being caused by extreme annoyance as some have suggested".

- "In Implications, it is inferred from the resident observations that the important effects result from very low frequency infrasound, about 3 Hz or lower".

- "The measurements support the hypothesis developed in that the primary frequencies are very low, in the range of several tenths of a Hertz up to several Hertz. The coherence analysis shows

[44] *Ibid.,* p.6.

that only the very low frequencies appear throughout the house and are clearly related to the blade passage frequency of the turbine".[45]

- "The house is acting like a cavity and indeed at 5Hz and below, where the wave length is 200 ft or greater, the house is small compared to the wave length". [46]

- "Currently the wind turbine industry presents only A-weighted octave band data down to 31 Hz, or frequently 63 Hz, as a minimum. They have stated that the wind turbines do not produce low frequency sound energies. The measurements at Shirley have clearly shown that low frequency infrasound is clearly present and relevant. A-weighting is inadequate and inappropriate for description of this infrasound. . . . The International Electro-technical Commission (IEC) Wind Turbine measurement standard needs to include both infrasonic measurements and a standard for the instruments by which they are measured."

On October 14, 2014, the Brown County Board of Health declared the Shirley Wind Turbine Development "a Human Health Hazard for all people (residents, workers, visitors, and sensitive passersby) who are exposed to Infrasound/Low Frequency Noise and other emissions potentially harmful to human health."[47]

3. Cooper: Cape Bridgewater 2014

Acoustician Steve Cooper's study "The Results of an Acoustic Testing Program, Cape Bridgewater Wind Farm" (26 November 2014)[48] was similar to Kelley's project at

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[45] *Ibid.,* Appendix D by Schomer and Associates Inc.

[46] Walker *et al*., p.7.

[47] Brown County Code 38.01 , Brown County Ordinances, Chapter 38, relating to Public Health Nuisance (section (b) Human Health Hazard): "a substance, activity or condition that is known to have the potential to cause acute or chronic illness or death if exposure to the substance, activity or condition if not abated".

[48] Cooper, S. "The Results of an Acoustic Testing Program, Cape Bridgewater Wind Farm, 44.5100.R7:MSC". Prepared for Energy Pacific (Vic) Pty Ltd, Melbourne, Vic., 26 November, 2014.

Boone in that he had been called in by the turbine operator, Pacific Hydro, to investigate noise complaints at three houses without restriction and with the co-operation of the wind turbine operator and the local residents. Monitoring both inside and outside of homes was completed over nine weeks using both internal and external locations, including a number of nights inside peoples' homes. The wind turbines were shut down for part of the time in order to carry out maintenance work on cables. It determined "the actual physical parameters involved in the measurement, interpretation and assessment of wind farm noise (audible and infrasound) on persons" in 235 pages with 6 technical annexures (491 pages). It identified infrasound "as a standard and normal part of the emissions of a wind farm. The character of the infrasonic emissions is identified as being measurably different from 'ordinary' wind; that is, infrasound generated by/from turbines consists of trains of pressure pulses and must be measured through narrow-band analysis and interpreted accordingly. Standard measures with third-octave bands and G-weighting are found to be not valid identifiers/measures of wind turbine affected wind noise".[49]

Using the diarized residents' one to two hourly observations when they felt well and when they didn't, the study identified 'sensation' (including headache, pressure in the head, ears or chest, ringing in the ears, heart racing, or a sensation of heaviness) as the major form of disturbance from the wind farm.

It also found a trend between high levels of disturbance (severity of "sensation") and changes in the operating power of the wind farm.

The study identified that the infrasound inside the houses was subaudible. Using narrow band analysis in the infrasound region "the measurement results clearly show a *periodic pattern in the infrasound* (the wind turbine signature) whilst the natural

[49] Letter from Bob Thorne to Steve Cooper, 21 January, 2014.

environment for infrasound has no such periodic patterns".[50] Cooper called this the WTS (Wind Turbine Signature) which is not present when the turbines are shut down. Like Kelley, he observed that the WTS is characterized by modulation. By including narrowband analysis in the description of the acoustic environment, the study confirms that the infrasound obtained in a wind farm affected environment is different to that in a natural acoustic environment.

- "When placed in the concept of a dB(WTS) curve, there is agreement with the infrasound components of the turbine perception nominated by Kelly in 1982".[51]

- "In medical studies, the dB(A) level measurement inside dwellings is of no assistance in such studies. . . . The use of dB(A) for the assessment of large industrial wind turbines does not address low frequency noise (LFN) or infrasound due to the filter characteristics of the A-weighting curve".[52]

- "Investigations into the infrasound issue associated with the wind turbines also require consideration of the noise levels inside buildings. In some cases the internal noise levels are higher than external, whilst for other sites the internal levels are marginally below that recorded externally – but not to the extent as the reduction in dB(A) values".[53]

He found as Kelley had, from testing inside buildings that

- "Due to building elements having an attenuation at low-frequencies much lower than that of high frequencies, the external spectra from outside a dwelling changes in its spectral shape when measured inside a dwelling, such that where there is a broadband noise outside then

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[50] *Ibid., p. 215.*
[51] *Ibid.,* p. v.
[52] *Ibid.,* p. 220.
[53] *Ibid.*

inside the dwelling the noise becomes predominantly a low frequency noise by the elimination of mid and high frequency components".[54]

Monitoring during the shutdown period

> ". . . permitted the opportunity to obtain noise data of the natural environment under various wind conditions, which would not be available during normal operations because of the operation of the turbines. The residents' observations during the shutdown periods identify there was no appreciable impact in terms of noise, vibration or sensation inside the buildings or the external yard area".[55]

The shutdown also allowed Cooper to make the same differentiation Kelley had between the characteristics of the infrasound emitted by the wind turbine (called the Wind Turbine Signature-- WTS) and the naturally occurring background infrasound.

> "Utilizing the Cape Bridgewater narrow band results superimposed onto the 1/3 octave band results shows there is a difference between the natural environment and a wind farm affected environment in the infrasound region. Therefore one cannot claim that infrasound levels in the natural environment are similar to that of wind farm affected environments."[56]

The unique infrasound 'wind turbine signature', was found to be present in the homes, and linked it to the diarized 'sensations' felt by the residents.

> "When placed in the concept of a dB(WTS) curve, there is agreement with the infrasound components of the turbine perception nominated by Kelley in 1982".[57]

[54] *Ibid.,* p. 46.
[55] *Ibid.*, p. 53.
[56] *Ibid*., p. 197.
[57] *Ibid.*, p v.

In February, 2015, Dr. Paul Schomer wrote of the Bridgewater report:

> "This study finds that these 6 people sense the operation of the turbine(s) via other pathways than hearing or seeing, and that the adverse reactions to the operations of the wind turbine(s) correlates directly with the power output of the wind turbine(s) and fairly large changes in power output.
>
> Attempts may be made to obfuscate these simple points with such arguments as it cannot be proved that infra-sound is the cause of the discomfort. But that again is a specious argument. The important point here is that something is coming from the wind turbines to affect these people and that something increases or decreases as the power output of the turbine increases or decreases. Denying infra-sound as the agent accomplishes nothing. It really does not matter what the pathway is, whether it is infra-sound or some new form of rays or electro-magnetic field coming off the turbine blades. If the turbines are the cause, then the windfarm is responsible and needs to fix it. Anyone who truly doubts the results should want to replicate this study using independent acoustical consultants at some other wind farm, such as Shirley Wisconsin, USA, where there are residents who are self-selected as being very or extremely sensitive to wind turbine acoustic emissions".[58]

> "Some may ask, this is only 6 people, why is it so important? The answer is that up until now windfarm operators have said there are no known cause and effect relations between windfarm emissions and the response of people living in the vicinity of the windfarm other than those related to visual and/or audible stimuli, and these lead to some flicker which is treated, and 'some annoyance with noise.' This study proves that there are other pathways that affect some people, at least 6. The windfarm operator simply cannot say there are no known effects and no known people affected. One person affected is a lot more than none; the existence of just one cause-and-effect

[58] Schomer, P. "The Results of an Acoustic Testing Program, Cape Bridgewater Wind Farm
Prepared for Energy Pacific by Steve Cooper, The Acoustic Group
A Review of this Study and Where It Is Leading". 10 February, 2015.

pathway is a lot more than none. It only takes one example to prove that a broad assertion is not true, and that is the case here. Windfarms will be in the position where they must say: 'We may affect some people.' And regulators charged with protecting the health and welfare of the citizenry will not be able to say they know of no adverse effects. Rather, if they choose to support the windfarm, they will do so knowing that they may not be protecting the health and welfare of all the citizenry".[59]

Stephen Ambrose observed that the correlation of human response journal entries with scientific waveform analysis in the Bridgewater study clearly shows hearing is not limited to audible sounds and that it goes far beyond the 1980s Neil Kelley et al. studies that identified operating wind-turbines can produce airborne transmissions that humans detect as "sensations".[60]

IV. Medical evidence on chronic infrasound exposure

World Health Organization: concerns about low frequency noise exposure

The 1999 World Health Organization (WHO) report "Guidelines for Community Noise" makes the following observations:

- "It should be noted that a large proportion of low-frequency component in a noise may increase considerably the adverse effects on health".[61]

- "The evidence on low frequency noise is sufficiently strong to warrant immediate concern". [62]

[59] Schomer, P. "Further comments on the Cape Bridgewater Wind Farm Study--Muddying the waters The Cooper report on the Cape Bridgewater Wind Farm. 2015.
[60] Stephen Ambrose letter to Steve Cooper dated January 22, 2015.
[61] Berglund, B, Lindvall, T, and Schwela, D, Ed. "Guidelines for Community Noise". World Health Organization, Geneva, 2000, p. xiv.
[62] *Ibid.,* p.35.

- “It should be noted that low-frequency noise . . . can disturb rest and sleep even at low sound pressure levels”.[63]

- “Other primary physiological effects can also be induced by noise during sleep, including increased blood pressure; increased heart rate; … vasoconstriction; …cardiac arrhythmia”.[64]

- “Special attention should also be given to the following considerations: . . .
  c. Sources with low-frequency components. [Sleep] disturbances may occur even though the sound pressure level during exposure is below 30 dBA”.[65]

- “After prolonged exposure, susceptible individuals in the general population may develop permanent effects, such as hypertension and ischaemic heart disease. . .”. [66]

- "For noise with a large proportion of low frequency sounds a still lower guideline (than 30dBA) is recommended."

- " When prominent low frequency components are present, noise measures based on A-weighting are inappropriate."

The DEFRA Report, 2003

“A Review of Published Research on Low Frequency Noise and its Effects” by Leventhall *et al.* published by DEFRA in 2003, stated:

[63] *Ibid.,* p. xii.
[64] *Ibid.,* p. x.
[65] *Ibid.,* p. 28.
[66] *Ibid.* p. x. See Babisch 1998 a; Babisch 1998b; Babisch et al. 1999; and Thompson, 1996.

- "The effects of infrasound or low frequency noise are of particular concern because of its pervasiveness due to numerous sources, efficient propagation, and reduced efficiency of many structures (dwellings, walls, and hearing protection) in attenuating low frequency noise compared with other noise".[67]

- "Exposure to low frequency noise in the home at night causes loss of sleep". [68]

In the 2003 DEFRA report he noted:

- "It is possible that body organs resonate within the low frequency range. Complainants of low frequency noise sometimes report a feeling of vibrations through their body".[69]

Citing the work of Inukai *et al*., (2000) and Nakamura and Inukai, (1998), Leventhall noted that there are

> "four main subjective factors in response to low frequency noise: auditory perception, pressure on the eardrum, perception through the chest and more general feeling of vibration".[70]

His report concluded:

- "There is no doubt that some humans exposed to infrasound experience abnormal ear, CNS, and resonance induced symptoms that are real and stressful. If this is not recognised by investigators or their treating physicians, and properly addressed with understanding and

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[67] Leventhall, G, Pelmear, P, & Benton, S. "A Review of Published Research on Low Frequency Noise and its Effects Report for Defra". Published by the Department for Environment, Food and Rural Affairs, (DEFRA), May, 2003, p. 54.
[68] Leventhall *et al* DEFRA review, p. 54.
[69] Leventhall, G, Brown, F, and Kyriakides, K. " Somatic responses to low frequency noise". *Proc ICA,* Madrid, 1977.
[70] Leventhall *et al* DEFRA review, p. 32.

sympathy, a psychological reaction will follow and the patient's problems will be compounded".[71]

Vibrations of 0.5 Hz to 80 Hz have significant effects on the human body

As pointed out by Professor Alan Hedge, of Cornell University,

> "every object (or mass) has a resonant frequency. When an object is vibrated at its resonance frequency, the maximum amplitude of its vibration will be greater than the original amplitude (i.e. the vibration is amplified). Vibrations in the frequency range of 0.5 Hz to 80 Hz have significant effects on the human body".

> "Individual body members and organs have their own resonant frequencies and do not vibrate as a single mass, with its own natural frequency. This causes amplification or attenuation of input vibrations by certain parts of the body due to their own resonant frequencies. Vibrations between 2.5 and 5 Hz generate strong resonance in the vertebra of the neck and lumbar region with amplification of up to 240%. Vibrations between 4 and 6 Hz set up resonances in the trunk with amplification of up to 200%. Vibrations between 20 and 30 Hz set up the strongest resonance between the head and shoulders with amplification of up to 350%.
> Whole body vibration may create chronic stresses and sometimes even permanent damage to the affected organs or body parts".

ISO 2631 (International Organization for Standardization) Human Response to Whole Body Vibration (WVB) (parts 1, 2, and 4) sets limits to the maximum possible exposure allowed for whole-body vibration including 'severe discomfort boundaries' for 8-hour, 2-hour and 30-minute WBV exposures in the 0.1 Hz to 0.63 Hz range.

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[71] *Ibid.,* p.60.

> "The exposure limit is the lowest for frequencies between 4-8 Hz because the human body is most sensitive to WBV at these frequencies. Suspected health effects of whole body vibration include: blurred vision; decrease in manual coordination; drowsiness (even with proper rest); low back pain/injury; insomnia".[72]

In 2006 Leventhall commented that "fluctuating audible sounds or amplitude modulations are the routine characteristic of IWTs and may be disturbing and stressful to exposed individuals".[73]

At a public hearing in Wisconsin in 2009[74], Leventhall stated that he was happy to accept the symptoms reported by individuals living near wind turbines including sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic episodes associated with sensations of internal pulsation or quivering when awake or asleep, "as they have been known to me for many years as the symptoms of extreme psychological stress from environmental noise, particularly low frequency noise".[75]

How sleep disturbance undermines health

In a 2014 article in the Lancet, Basner *et al.* confirmed:

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[72] Hedge, A. "Notes for students", Department of Department of Design and Environmental Analysis, Cornell University. (http://ergo.human.cornell.edu/studentdownloads/dea3500pdfs/whole-bodyvi), p.2-3.

[73] Leventhall, G. "Infrasound from wind turbines: Fact, fiction or deception?" *Canadian Acoustics*, *34*, 29-36, 2006.

[74] Leventhall, G. "Wind turbine syndrome: An appraisal *Hearing before the Public Service Commission of Wisconsin"*, 2009.

[75] However, in spite of these earlier statements, Professor Leventhall has subsequently appeared as an expert witness in various court proceedings for wind developers. Leventhall's evidence asserting that the nocebo effect was causing the reported symptoms was most recently heard in the Bull Creek case before the Alberta Utilities Commission in November, 2013. Rick James has observed: "The studies and reports by acousticians not affiliated with or sponsored by the wind industry warrant substantially more weight because they are less subject to issues of 'group think' or confirmation bias".

- “Evidence of the non-auditory effects of environmental noise exposure on public health is growing. Observational and experimental studies have shown that noise exposure leads to annoyance, disturbs sleep and causes daytime sleepiness, affects patient outcomes and staff performance in hospitals, increases the occurrence of hypertension and cardiovascular disease, and impairs cognitive performance in schoolchildren”.[76]

  “Sleep disturbance is thought to be the most deleterious non-auditory effect of environmental noise exposure . . . because undisturbed sleep of a sufficient length is needed for daytime alertness and performance, quality of life, and health. Human beings perceive, evaluate, and react to environmental sounds, even while asleep”.[77]

  “Taken together, the present review provides evidence that noise not only causes annoyance, sleep disturbance, or reductions in quality of life, but also contributes to a higher prevalence of the most important cardiovascular risk factor arterial hypertension and the incidence of cardiovascular diseases. The evidence supporting such contention is based on an established rationale supported by experimental laboratory and observational field studies, and a number of epidemiological studies. Meta-analyses have been carried out to derive exposure–response relationships that can be used for quantitative health impact assessments. Noise-induced sleep disturbance constitutes an important mechanism on the pathway from chronic noise exposure to the development of adverse health effects. [78]

[76] Basner, M, Babisch, W, Davis, A, Brink, M, Clark, C, Janssen, S, Stansfeld, S. “Auditory and non-auditory effects of noise on health. *Lancet* 2014; 383: 1325–32

[77] Basner, *et al.* “Cardiovascular effects of environmental noise exposure”. *Noise literature review 2011-2014, 835.*

[78] Münzel, T, Gori, T, Babisch, W, and Basner, M. “Cardiovascular effects of environmental noise exposure”. *European Heart Journal* (2014) 35, 829–836.

How subaudible infrasound is perceived in humans

In 2004, H. Møller and C. S. Pedersen[79] of the Department of Acoustics, Aalborg University wrote and article on "Hearing at Low and Infrasonic Frequencies":

- "The ear is the primary organ for sensing infrasound . . . the perceived character of a sound that changes with decreasing frequency. Pure tones become gradually less continuous, the tonal sensation ceases around 20 Hz, and below 10 Hz it is possible to perceive the single cycles of the sound. A sensation of pressure at the eardrums also occurs. The dynamic range of the auditory system decreases with decreasing frequency".

- "The hearing becomes gradually less sensitive for decreasing frequency, but there is no specific frequency at which the hearing stops. Despite the general understanding that infrasound is inaudible, humans can perceive sound also below 20 Hz. This applies to all humans with a normal hearing organ, and not just to a few persons. The perceived character of the sound changes gradually with frequency. For pure tones the tonal character and the sensation of pitch decrease with decreasing frequency, and they both cease around 20 Hz. Below this frequency tones are perceived as discontinuous. From around 10 Hz and lower it is possible to follow and count the single cycles of the tone, and the perception changes into a sensation of pressure at the ears. At levels 20-25 dB above threshold it is possible to feel vibrations in various parts of the body, e.g. the lumbar, buttock, thigh and calf regions".[80]

- "A feeling of pressure may occur in the upper part of the chest and the throat region. Spontaneous reactions from subjects and visitors in the author's laboratory as well as their own

[79] Møller, H & Pedersen, C. "Hearing at Low and Infrasonic Frequencies". Department of Acoustics, Aalborg University, 2004, P. 54.
[80] *Ibid*. pp. 54-55.

experience suggest that vibrotactile sensations and a feeling of pressure may also occur in the upper part of the chest and in the throat region".[81]

- "It has also been shown that the hearing threshold may have a microstructure that causes a person to be especially sensitive at certain frequencies. These two phenomena may explain observations from case studies, where individuals seem to be annoyed by sound that is far below the normal threshold of hearing".

- "In addition to direct detection, infrasound may be detected through amplitude modulation of sound at higher frequencies. This modulation is caused by the movement of the eardrum and middle-ear bones induced by the infrasound, which results in changes of transmission properties. . . . a sound, which is inaudible to some people, may be loud to others. There is a reasonable agreement between data also below this frequency, and contours have been proposed down to 2 Hz".[82]

- "Under certain atmospheric conditions, e.g., temperature inversion, the noise may be more annoying and—in particular the low-frequency part—propagate much further than usually assumed". [83]

In a 7-year study that collected acoustic data at a number of the homes, so that cumulative acoustic exposures for some study participants could then be estimated, Robert Thorne concluded:[84]

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[81] Møller & Pedersen *op. cit.* p. 50
[82] *Ibid.* p. 55.
[83] Møller, H, Pedersen, C. "Low-frequency wind-turbine noise". *J. Acoust. Soc. Am*., Vol. 129, No. 6, June 2011, p. 3743.
[84] Thorne, R. "Wind Farm Noise and Human Perception A Review". Noise Measurement Services, Pty. Ltd, Queensland, Australia, 2013, p. 92.

- "The findings suggest that the individuals living near the wind farms of this study have a degraded Health-Related Quality of Life through annoyance and sleep disruption and that their health is significantly and seriously adversely affected (harmed) by noise. Based on the results of the study it is argued that, when exposed to wind farm noise and wind turbine generated air pressure variations, some individuals will more likely than not be so affected that there is a known risk of serious harm (also termed 'significant adverse effect') to health."

Nissenbaum & Hanning

In 2012, two medical doctors[85] published in a peer reviewed journal, the findings of their stratified cross-sectional study involving the health effects of persons living within 1100 meters of the Vinylhaven and Mars Hill Wind Turbine Projects in Aroostook County, Maine, which consists of 28 wind turbines.[86] They also presented their research at the 10th International Congress on Noise as a Public Health Problem (ICBEN) 2011, London, UK. They concluded:

> "The noise emissions of IWTs disturbed the sleep and caused daytime sleepiness and impaired mental health in residents living within 1.4 km of the two IWT installations studied. Industrial wind turbine noise is a further source of environmental noise, with the potential to harm human health. Current regulations seem to be insufficient to adequately protect the human population living close to IWTs. Our research suggests that adverse effects are observed at distances even beyond 1 km. Further research is needed to determine at what distances risks become negligable, as well as to better estimate the portion of the population suffering from adverse effects at a given distance".

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[85] Michael Nissenbaum MD, Northern Maine Medical Center, Fort Kent, Maine, USA and Christopher Hanning, MB, BS, MD, University Hospitals of Leicester, Leicester, UK.
[86] Nissenbaum, M, Aramini, J, Hanning, D. "Effects of industrial wind turbine noise on sleep and health". *Noise and Health International Journal*, September-October 2012.

In a sworn affidavit before the Court of Queen's Bench Judicial Centre of Saskatoon, Saskatchewan, Dr Nissenbaum stated:

> "It is my professional opinion that there is a high probability of significant adverse health effects for those whose residence is located within 1100 meters of a 1.5 MW turbine installation based upon the experiences of the subject group of individuals living in Mars Hill, Maine. It is my professional opinion, based on the basic medical principle of having the exposure to a substance proven noxious at a given dose before risking an additional exposure, that significant risk of adverse health effects are likely to occur in a significant subset of people out to at least 2000 meters away from an industrial wind turbine installation. These health concerns include:

- Sleep disturbances/sleep deprivation and the multiple illnesses that cascade from chronic sleep disturbance.
- These include cardiovascular diseases mediated by chronically increased levels of stress hormones, weight changed, and metabolic disturbances including the continuum of impaired glucose tolerance up to diabetes.
- Psychological stresses which can result in additional effects including cardiovascular disease, chronic depression, anger, and other psychiatric symptomatology.
- Increased headaches.
- Unintentional adverse changes in weight.
- Auditory and vestibular system disturbances.
- Increased requirement for and use of prescription medication".

Summing up by a medical doctor and sleep specialist

Dr. Christopher Hanning BSc, MB, BS, MRCS, LRCP, FRCA, MD has served as Director of the Sleep Clinic and Laboratory at Leicester General Hospital, one of the largest sleep disorders clinics in the UK.[87] In 2013 he presented the following evidence under oath to the Alberta Utilities Commission Hearing for the Bull Creek wind development.

His opening statement provides an appropriate summary of the medical evidence[88]:

> “I do not think that there is any dispute that adequate sleep is essential for human health and well being. There is a vast literature on the effects of sleep loss on brain function, the heart and circulation, metabolism to name but a few. Anything that causes sleep loss will lead to ill health.
>
> “I do not think that there is any dispute either that wind turbine noise emissions can disturb sleep and that this is the principle reason for requiring a separation distance between turbines and homes. The separation distance is determined either as an actual minimum distance or by reference to a calculated noise level that has been deemed to be acceptable. The acceptable noise level is derived from a variety of sources, in particular studies of the effects of traffic noise. It must be remembered that the acceptable noise levels used in regulations and guidelines relating to wind turbines have only been derived from theoretical considerations and not from experiment at actual wind turbine sites with actual people. Until recently, there has been no experimental verification that the recommended noise levels are in fact safe and have no discernable impact on human sleep.

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[87] He has served as first Honorary Secretary of the British Sleep Society; Chairman of the Primary Care Sleep Group; Examiner Part II (Primary) FRCA Examination; Regional Adviser to the Royal College of Anaesthetists; Member, Royal College of Anaesthetists Advisory Appointments Committee Panel; Member, Royal College of Anaesthetists Hospital Accreditation Panel; Chairman, Independent Research Ethics Committee, PPD Pharmaco; Medical Adviser, UK Narcolepsy Association; and Chairman and Panellist, General Medical Council, Fitness to Practice Panels.

[88] Opening Statement of Dr Christopher Hanning BSc, MB, BS, MRCS, LRCP, FRCA, MD. Alberta Utilities Commission Hearing for development of wind power plant and associated substation in the Provost area (“Bull Creek”). Proceeding Number 1955 18th November 2013.

“In my expert opinion, there is now more than sufficient evidence to conclude that wind turbine noise impairs the sleep and health of residents living at distances greater than those proposed in the project under consideration. There is a real risk to the sleep and health of any resident living within 1.5km of a turbine. I base this opinion on three main strands of evidence.

“First, the anecdotal evidence. Dr Phillips has dealt with this so I will not deal with further with it except to state that I find it convincing. Secondly, the various general surveys taken around wind turbine installations including those of Pedersen and van den Berg in Europe and more recently by Morris and Schneider in Australia, all of which point to problems with sleep but did not use any specific test instruments for sleep quality. Again, I find the weight of evidence convincing as it all points in the same direction.

Thirdly, those studies that have used control groups and specific test instruments for sleep. Dr Shepherd’s peer-reviewed study used the WHO Quality of Life test instrument which includes elements related to sleep and shows unequivocally that those living within about 1.4km of the turbines had a lower quality of life than those living several kilometres away. Dr Nissenbaum’s peer-reviewed study, to which I contributed and am an author, showed convincingly that those living within about 1.5km of wind turbines had worse sleep than those living several kilometres away. This study looked at two different wind turbine facilities.

“Dr Bigelow’s study, sponsored by the Ontario Government at 8 wind turbine sites, used similar sleep specific test instruments to the Nissenbaum study. The results are very similar and confirm that the closer one lives to a wind turbine installation, the more likely you are to have poor sleep. This study is complete and the results have been presented as a poster. Dr Ollson has, most unfairly, characterised this as a student study. It is not. The poster presents the results of the largest study thus far to examine the effects of wind turbine noise on sleep using test instruments specific for sleep conducted by experienced investigators who consulted widely in designing the study including with myself. BluEarth’s [the developer’s] witnesses claim that there is insufficient evidence to prove a causal link between wind turbine noise and sleep disruption. The only study of wind turbine noise and well being which does not demonstrate harm is that of Mroczek. The study group included subjects not exposed to turbine noise and the conclusions are not justified by the data. Every other study shows harm. There is no single, well conducted, controlled and reliable piece of original research which shows that wind turbines do not cause harm at the distances proposed here. Not one.

“With respect to causality, affected subjects improve when exposure ceases and relapse when exposure restarts. This is prima facie evidence of causality. The studies of Pedersen as well as those of Nissenbaum and Bigelow show a clear dose-response relationship. This too is prima facie evidence of causality.

“I am not a lawyer but my work with the United Kingdom General Medical Council gives me a good understanding of standards of proof. In a situation such as this where the consequence of the wrong decision is highly likely to be harm to the nearby residents, the civil standard of proof is appropriate, the balance of probabilities. In my expert opinion, the scientific evidence more than meets this evidentiary test.

“Wind turbine noise from turbines of the size proposed in the project under consideration has a high risk of disturbing the sleep and impairing the health of those living within 1.5km. There are at least 25 occupied properties meeting this criterion and I advise that the proposal be refused to safeguard the occupants”.

Conclusion

Based on the information presented above, infrasound generated by wind turbines must be considered a potential direct cause of the adverse health reactions widely reported from wind turbine host communities.

Now that so many indicators point to infrasound as a potential agent of adverse health effects, it is critical to re-examine the approach to this aspect of wind turbine operation, revise regulations, and immediately implement protective public health measures based on the precautionary principle.

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ABOUT THE AUTHOR

Keith Stelling is an independent researcher and writer with many articles on health issues published in Canada and the United Kingdom.

After graduating from McMaster University with an Honours B.A. and M.A., he completed three years of post graduate studies at the School of Phytotherapy in England, obtaining the Diploma in Phytotherapy and becoming the first Canadian member of the National Institute of Medical Herbalists of Great Britain and the College of Practitioners of Phytotherapy (England). After returning to Ontario he taught courses, ran his own practice and founded and edited the Canadian Journal of Herbalism. He also served as a peer reviewer on the editorial board of the British Journal of Phytotherapy, and as a member of the Government of Canada Second Expert Advisory Committee on Herbs and Botanical Preparations, presented to the House of Commons Standing Committee on Health, and contributed a number of monographs to the Canadian Pharmacists Association and the Canadian Medical Association guide to botanical medicine (Chandler F, editor. 2000. "Herbs: Everyday Reference for Health Professionals").

After retiring to rural Bruce County, he became aware of the health and environmental issues associated with nearby wind turbines and has spent the last nine years researching these concerns. He was appointed a citizen member of the Multi-municipal Wind Turbine Working Group comprised of elected municipal councillors from Bruce, Grey, and Huron Counties. He was a founding member of Wind Concerns Ontario and in 2008 he formed a local conservation group, "The Friends of Arran Lake" with the aim of preventing the significant wildlife habitat in his neighbourhood from being degraded by a wind turbine development.

His research papers include:

Stelling, Keith (2012). *"***Questions arising from the Auditor General's 2011 Report on Renewable Energy Initiatives".** With comprehensive and detailed evidence gathered independently from inside the Ministry of Energy– much of it previously unavailable to the public– the Auditor General's Report unambiguously challenges both the rationale and implementation of the Green Energy Act. The Act has been promoted as a mechanism for cutting greenhouse gas emissions, increasing job opportunities, and creating a competitive business environment. However the Auditor General's investigators found little evidence that these objectives have been or would be realized.
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survival or reduced breeding productivity-- a particular concern for declining populations. The cumulative effects of multiple on- and off-shore wind developments have not been considered. Download original document: "Threats from industrial wind turbines to Ontario's wildlife and biodiversity"

Stelling, Keith (2010). **"What went wrong with Ontario's energy policy? Comparing spin and reality".** By referring to the economic experience of those European countries that have vigorously promoted wind energy over the last two decades, this report demonstrates that the decisions of the Ontario government did not take into consideration the reality of introducing large scale industrial wind energy onto the grid. In fact, the government's enthusiasm to embrace what it claimed to be cheap, "clean", environmentally benign electricity at the same time as diminishing CO2 emissions appears to have ignored all the realistic warnings from electricity production professionals it received. (*Predictions of rising electricity costs and job losses have become reality with Ontario having the highest electricity costs in North America).* Download original document: "What went wrong with Ontario's energy policy?"

Stelling, Keith and Krogh, Carmen (2009). "**Summary of Recent Research on Adverse Health Effects of Wind Turbines".** Authorities and politicians in Ontario have been repeatedly warned that industrial wind turbines are having an adverse effect on the health of those living nearby. Health complaints are not peculiar to this province but are consistent throughout the world wherever large industrial wind turbines have been installed. Contrary to the claims of the industry, there is a growing body of peer-reviewed research substantiating these health claims. This report attempts to catalogue the most recent. *A generally acknowledged major concern about wind turbine disturbance centres around the low frequency noise projected from this heavy industrial machinery. Until recently measurements of this type of noise have seldom been carried out near wind turbines. There is already ample scientific evidence that low frequency noise is a cause of sleep disturbance in humans.* The evidence also suggests that long term exposure normally leads to serious health problems. *Research on animals indicates that basic survival functions such as hunting, self protection and reproduction are interrupted by low frequency noise exposure.* Download original document: "Adverse Health Effects of Wind Turbines"

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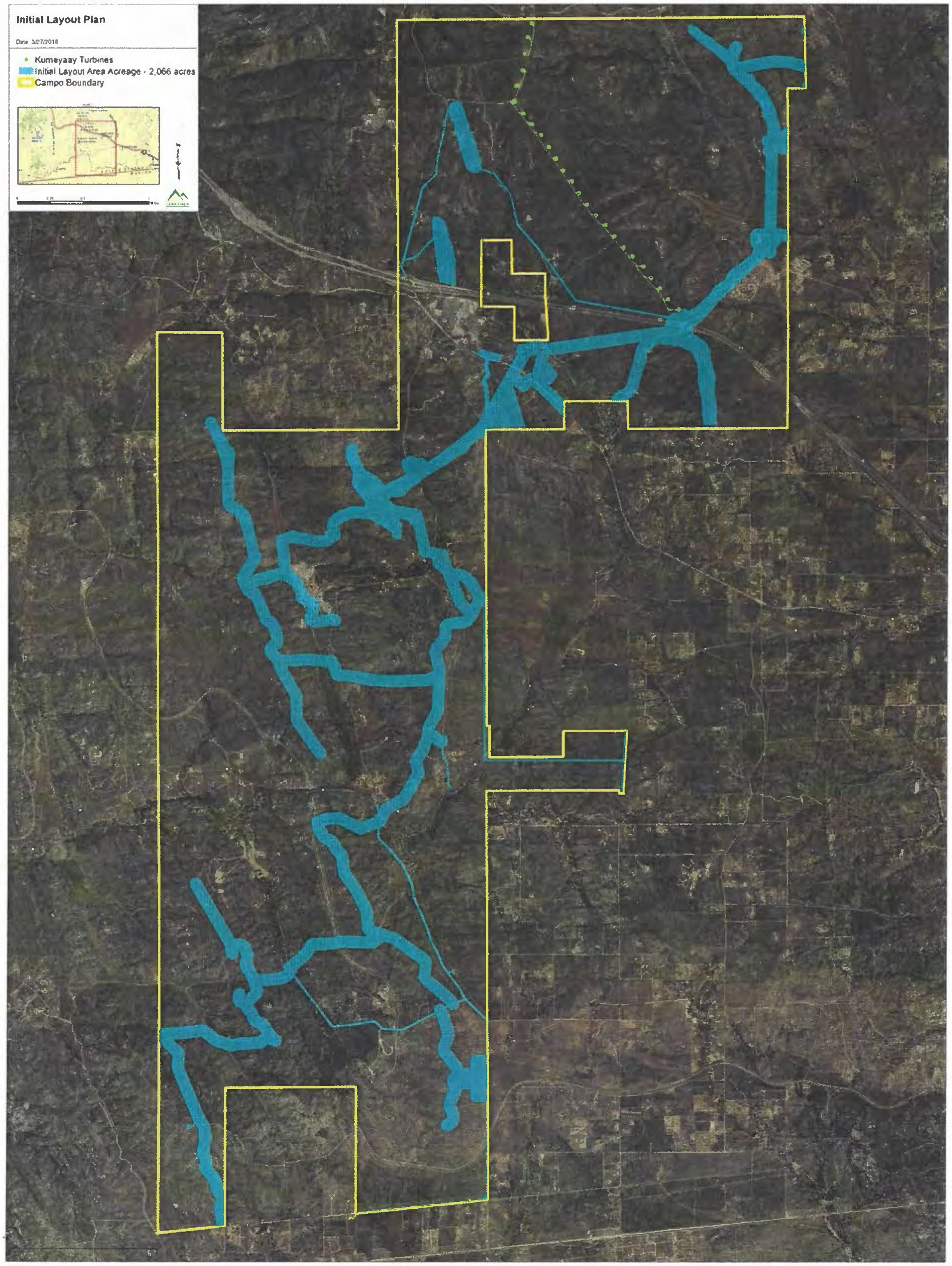
Stelling, Keith (2008). "**Arran Lake Wetlands Complex: a study of a sensitive wildlife habitat under threat**". An 82 page study of an important migratory stopover, which is also a functional natural heritage system, and is comprised of three provincially significant ANSIs (designated areas of natural and scientific interest); illustrated with photographs of the area; listing 21 species at risk and how they would be threatened by a proposed wind turbine development.

Stelling, Keith (2007) "**Calculating the Real Cost of Industrial Wind Power"**
An information update for Ontario Electricity Consumers Studies challenging the assumption upon which the ecological value of commercial wind power is based: that it does not reduce carbon emissions because it requires fossil-fuelled back up; that wind energy is not cheap but very expensive and will raise consumer electricity costs to economically destructive levels. Download original document: "Calculating the Real Cost of Industrial Wind Power"

INITIAL LAYOUT PLAN



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	Printed Name	Signature	Address	Comment	Date
1	Gary A Cogbill	[signature]	38390 Old Hwy 80	Keep Them Out!	12-14-18
2	Jennifer Schulz	[signature]	2246 Tierra Heights Rd	No turbines	12/14/18
3	Robert Tucker	[signature]	38775 Bypass Rd		12-16-18
4	Michele Perez	[signature]	PO Box 1042	hell no	12/14/18
5	Robert D. Minton	[signature]	PO Box 1304 Boulevard CA		12-16-18
6	Neal Shields	[signature]	PO Box 1043 Boulevard CA	Not in our House	12-16-18
7	Pete Champ	[signature]	PO Box 1211 Boulevard		12-16-18
8	Fred Chavez	[signature]	PO Box 1409	No turbins	12-16-18

PAGE 1

	Printed Name	Signature	Address	Comment	Date
9	Audra Burgio	Audra Burgio	38763 Bahia Vera Rd Boulevard, CA 91905	* Please see action Petition filed for action	12-16-18
10	Linda Shannon	Linda Shannon	PO Box 1527 Boulevard, Ca	NO Turbines	12-16-18
11	SHARON L. MADSEN	Sharon L Madsen	P.O. BOX 1299 38232 Tierra Real Rd Boulevard CA 91905	No turbines	12/16/18
12	GERALD N. MADSEN	Gerald N Madsen	Box 1299 38232 TIERRA REAL RD BOULEVARD CA 91905	NO TURBINES	12/16/18
13	Rose Tapia	[signature]	1237 Tierra Real Ln. BOULEVARD CAL. 91905	No TURBINES	12-16-18
14	Frank Jones	[signature]	38204 Tierra Real Rd. Boulevard, CA 91905	I Like my sunset view	12-16-18
15	Nalin Flaman	[signature]	38202 Tierra Real Rd Boulevard CA. 91905	worried about health w/ energy emissions etc.	12-16-18
16	William Swycaffer	[signature]	38220 Tierra Real Rd. Boulevard, CA	NO turBINES	12/16/18
17	Michele Swycaffer	[signature]	38220 Tierra Real RD Boulevard ca	NO Turbines	12-16-18
18	Teresa Briggs	Teresa Briggs	1310 Tierra Del Sol Rd Boulevard, CA 91905	No Turbines	12-16-18
19	Steven Briggs	[signature]	1310 Tierra Del Sol Rd Blvd CA 91906	NO TURBin.	12-16-18
20	Monica Albar	[signature]	P.O. Box 1045 Boulevard, CA, 91905	No to Tubines	12/16/18
21	Jason Fordyce	[signature]	PO. box 1045 Boulevard CA, 91905	NO to TURbines	12-17-18
22	MARTY KENDALL	[signature]	PO Box 1401 Boulevard CA. 91905	Sucky Sucky	12-19-18
23	Ed Tisdale	Ed Tisdale	P.O. Box 1175 Boulevard	You R Turbines Shows ZERO Respect	12-21-18
24	Tracy Tisdale	[signature]	Po. Box 961 Boulevard CA 91905		12-21-18

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	Printed Name	Signature	Address	Comment	Date
25	DONNA TISDALE	Donna Tisdale	PO BX 1275 BOULEVARD CA 91905	NO TURBINES	12-16-18
26	WILLIAM FALT	William Falt	37675 MOON VLY RD BOULEVARD, CA 91905	NO TURBINES	12-16-18
27	Lorelei Howard	[signature]	1601 Jewel Valley Rd	Stop Turbines	12-15-18
28	Glenn Howard	Glenn Howard	1601 Jewel Valley R	NO Turbines	12-16-18
29	Deborah Shaw	Deborah Shaw	1605 Jewell Vly Rd	Enough!	12-16-18
30	TAMMY Daubach	Tammy Daubach	39954 Ribbonwood Rd. Blvd, 91905	CRAZY!	12-16-18
31	Michelle Daubach	[signature]	39954 Ribbonwood Rd, 91905	Pro Corporate Onsite Energy Gen.	12-16-18
32	STAN Buddenbohm	[signature]	37341 HWY 94 91905	NO TURBINES	12-16-18

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	Printed Name	Signature	Address	Comment	Date
33	LARRY DOUGLAS	Larry Douglas	38511 ALTA VEGA Rd.	No TURBINES	12-15-18
34	Paul Unmack	[illegible]	3074 Wharton Butte, MT	Bad!	12-15-18
35	DUSTIN WALKER	[illegible]	39211 CLEMENTS ST.	HORRIBLE INVESTMENT HORRIBLE SCENERY HORRIBLE FIRE HAZARD	12-15-18
36	John Dolan	[illegible]	38204 Tierra Real Rd	NO TURBINES	12-16-18
37	Willy Shaw	WMS	40 crestwood rd	environmental impact	12-16-18
38	Pamela Guy	Pamela Guy	2975 Ribbonwood RD Boulevard	NO Turbines	12-16-18
39	RICHARD DART	[illegible]	39745 AVE DE ROBLES VERDES Boulevard	no Turbines	12.16.18
40	Patricia Grib	Patricia [illegible]	39605 OLD Highway 80 Boulevard, CA 91905	No more Turbines	12-14-18
41	Gina Butler	Gina Butler	2738 Ribbonwood Rd Boulevard	NO more!	12-15-18
42	Rex Butler	[illegible]	2738 Ribbonwood Rd. Boulevard Ca 91905	No more!	12-15-18
43	DAVID Elliott	D. Elliott	PO Box 937 BLVD CA. 91905	AGAIN! NO MORE PLEASE!	12-15-18
44	William Hernandez	[illegible]	Po Box 1575 91905	NO	12/10/18
45	FRANK DAVOLI	Frank Davoli	P.O. BOX 1180 91905	NO TURBINES!	12/15/18
46	Walt Henderson		BOX 1093	" "	12/15
47	[illegible]	JEFF MORRIS	2945 RIBBONWOOD PO BOX 1306	NO TURBINES	12/15
48	[illegible]	Rebecca Morris	2945 Ribbonwood Rd Blvd, CA 91905	NO Turbines	12/15/18
49	Alyssa Gantz	[illegible]	PO Box 575 Boulevard CA 91905	NO NO	12/15/18
50	Chris Borgio	[illegible]	38763 Alta Vega Rd.		12-15-18

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	Printed Name	Signature	Address	Comment	Date
51	Ron Hyman	[signature]	39548 Opalocka Rd Blvd, CA 91905	Strongly opposed to more turbines	12/17/18
52	Kevin LaClair	[signature]	39548 Opalocka Rd Blvd, CA 91905	Turbines are not good for our land or Health	12/17/18

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	Printed Name	Signature	Address	Comment	Date
53	TRAVIS POLEN	[signature]	P.O. BOX 1124 BOULEVARD CA, 91905	NOT THE RIGHT AREA FOR TURBINES.	12/17/18
54	Kaye Holmgren	[signature]	2537 Angel Dr. Boulevard, CA 91905	There are better areas for turbins	12/19/18
55	WILLIAM HOLMGREN	[signature]	2537 ANGEL DR BOULEVARD CA 91905		
56	HEATHER SCHWARZ	[signature]	964 tierra Del Luna Boulevard CA 91905	TOO MANY HOMES PEOPLE & HABITAT	12-19-18
57	Brad Schwartz	[signature]	964 TIERRA DE Luna		12-19-18
58	Christina Vickers	[signature]	44640 Calexico Ave	Not the right place	12-20-18
59	Anna Holmgren	[signature]	2537 Angel Dr. Boulevard, 91905	Not the right area for more turbines	12-20-18
60	JERRY [illegible]	[signature]	39551 old Hwy 80 Boulevard		12-20-18

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	Printed Name	Signature	Address	Comment	Date
61	FERNEY Obeso	[signature]	39537 old Hwy 80		12-20-18
62	Jacqueline Rivero	[signature]	1158 Tierra Del Sol Rd	to Close to home	12-20-18
63	Joseph Long	[signature]	1158 Tierra Del Sol RD	to close to home	12/20/18
64	Amanda Jackson	[signature]	1158 tierra del Sol RD	eye sore to close to homes	12-20-18
65	Jeremy Long	[signature]	1158 Tierra Del Sol RD	to close to home	12-20-18
66	Christina Rodriguez	[signature]	37839 Moon Valley Rd	to Close to home	12-20-18
67	Frances Lomely	[signature]	37839 Moon Valley Rd		12-20-18
68	Chris Rodriguez	[signature]	37839 Moon Valley rd	to Close to home	12-20-18
69	Russell Harris	[signature]	37748 Tierra Estrella		12-20-18
70	Donna Anselmi	[signature]	37748 Tierra Estrella	Too Close To Home	12/20/18
71	Jeanne Lewis	[signature]	686 Tierra Del Sol	" "	12/20/18
72	Mary L Ayers		664 Tierra Del Sol		12-20-18
73	Ted Tibbetts	[signature]	664 Tierra Del Sol	Bull XXXX	12/20/18
74	WALT BAYLESS	[signature]	510 TIERRA DEL SOL	TOO BIG	12-20-18
75	MARilyn Polen	[signature]	512 Tierra Del Sol Boulevard	Too close to homes - Lots of Health Iss. Noise	12-20
76	Byron Polen	[signature]	512 Tierra Del Sol Boulevard	Property Value health issues " " "	12-20
77	Adriana Polen	[signature]	1078 Mary Jane Ln Boulevard ca 91905	Too close to home	12/20/18
78	William Patrick	[signature]	Po Box 553 Boulevard CA 91905	To Close home	12 21 18

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	Printed Name	Signature	Address	Comment	Date
79	DEBI FORSBERG	D. Forsberg	1621 JEWEL VALLEY RD BOULEVARD, CA 91905		12-20-18
80	MICHAEL FORSBERG	M Forsberg	1621 JEWEL VALLEY RD BOULEVARD, CA 91905		12-20-18
81	Michele Strand	MStrand	2235 Tierra Hgts Rd Boulevard 91905	too tall and too close to homes	12/20/18
82	Amy Weisiger	[signature]	39235 Hwy 94 Boulevard CA 91905	TOO tall	12/20/18
83	Debs Weisiger	[signature]	39235 HWY 94 Blvd CA 91905	TO close to Homes	12/20/18
84	Marie Morgan	Marie Morgan	2912 Ribbonwood Rd. Boulevard, CA 91905	too LOUD	12/20/18
85	ROBERT S. MORGAN	[signature]	2912 Ribbonwood Rd Blvd, CA. 91905		12/20/18
86	Linda Shannon	Linda Shannon	2587 Ribbonwood Rd		12-20-18

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	Printed Name	Signature	Address	Comment	Date
87	David Shannon	David Shannon	2587 Ribbonwood Rd Boulevard, Ca.		12-20-18
88	Debbie Moran	Debbie Moran	39545 Clements St Boulevard, CA 91905		12-20-18
89	MICHAEL MORAN	Michael Moran	39545 CLEMENTS ST. BOULEVARD, CA. 91905		12-20-18
90	IRENA CATOS	[illegible]	2233 Tierra Heights Boulevard CA 91905		12-20-18
91	AAron Peterson	[illegible]	2235 Tierra Heights Rd	Blvd 91905	12-20-18
92	Joseph Flores	J. R. Flores	38808 OLD HWY 80 BOULEVARD CA 91905		12-21-18
93	James E. Blank	James E. Blank	" " "		12-21-18
94	Larry Monday	Larry Monday	2496 Tierra Heights Blvd Rd		12.21.18
95	Priscilla Monday	Priscilla Monday	2496 Tierra Heights Blvd		12.21.18

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	Printed Name	Signature	Address	Comment	Date
96	Skylar Middlebrook	[signature]	P.O. BOX 1077 Boulevard CA. 91905		12/15/18
97	Erin Aldridge	[signature]	38526 High Ridgehill Boulevard Ca 91905		12/18/18
98	Katie Webb	Katie Webb	39880 UCS Ranch Road Boulevard, CA 91905		12/19/18
99	Alex Short	[signature]	39838 Manzanita Drive		12/19/18
100	Jenene Lambert	[signature]	576 TDS Rd 91905		12-20-18
101	Dwight Swinland	Dwight Swinland	38763 Alta Vega Rd 91905		12-20

APPENDIX E

Transcript of Public Scoping Meeting

Public Scoping Meeting

for Preparation of

a Draft Environmental Impact Statement

to the Proposed

Campo Wind Energy Project

San Diego, California

Thursday, December 6, 2018, 6:00 PM

Campo Indian Reservation Tribal Hall

36190 Church Road

Campo, California 91906

Reported by: Veronica S. Thompson, CSR 6056

INDEX OF COMMENTERS

Campo, California, December 6, 2018, 6:19 PM

DAN "HAROLD" HALL: So what we're going to do -- how this is going to work is we're just going to kind of go in the order that we receive comments, and the mic will be passed to people.

And just a few suggestions here. One is just to really summarize your points. And, again, if you need to make more of a lengthy statement, again, it's recommended that you fill out a longer sheet or send in a letter or whatever if you go beyond the three minutes in terms of comments.

And, also, you need to address this table so that I can hear you clearly as well as -- the stenographer can as well.

And then, finally, I'm sure a lot of you have been through these types of hearings before, but it's not really a question-answer session. It's not a forum for debate. We're here basically to receive your input and your comments regarding this proposed project.

So with that, we'll go to the first commenter.

Benjamin Good?

LADY: He just got here, so could he be at the end?

DAN "HAROLD" HALL: Sure.

Nancy Good?

NANCY GOOD: That's me.
CHAD: And I can bring the microphone to you.
NANCY GOOD: I probably don't need it.
CHAD: Just in case.
DAN "HAROLD" HALL: What we found in this room -- it doesn't echo so much if you use the microphone.
NANCY GOOD: Okay. My question --
MAN: Can I approach that map? Because I don't even know where it's at. I haven't seen a detailed map. I can't even tell where that thing is at.
Do you have any detailed map with the distances from the different BIA 10?
MATT VALERIO: We're going to post this on our website.
MAN: Yeah, post it, but I can't even read it. It doesn't show anything on there that's a reference.
MAN: I think you're talking about private property.
MAN: How far from property sites and stuff? You don't have anything like that?
MATT VALERIO: Not yet, no. Nothing like that --
MAN: It's kind of hard to make comments on something where you can't even tell where it's at.

MATT VALERIO: So this is the only days, so we're trying to understand what topics you wanted us to look at.

MAN: And the topic is, where exactly is it at?

CHAD: Matt, do you want to go up and annotate on the map and point out where it is?

NANCY GOOD: I have no problem with you asking that question. I'm easy. And thanks for calling me "Miss."

LADY: Not all of the community members have access to computer. Is it possible to have this information mailed to us?

DAN "HAROLD" HALL: Certainly.

MATT VALERIO: So this is the I-8, and here are the existing Kumeyaay wind turbines.

And then -- yeah. And then these red areas, as I say, are the east lines, and you can see where they come. I mean, exactly what you're after in terms of --

LADY: Can I show him where his property is? I'll just walk up and show him.

THE REPORTER: I'm sorry, but I'm not getting identifications of these commenters.

(Discussion off the record.)

DAN "HAROLD" HALL: These are just informal.

These aren't any --

MATT VALERIO: I'll give you a little hand raise when you've got a minute left.

NANCY GOOD: I'm Nancy Good, and I live over on Old 80 right next to the Campo Indian Reservation. The back part of our property is adjacent to it.

My question is -- I'm looking in this class- -- in this room tonight, and I know my neighbors knew nothing about this.

How come this has not been brought forward in the community more than what it has? If it wouldn't have been for Donna stopping by my house last week, we would have not known about this meeting.

LADY: Same here.

NANCY GOOD: And, to me, that is not giving the people out here a voice as to what you're planning to do in our community and what it's going to do to their property value.

And that's all I have to say.

MATT VALERIO: Thank you.

DAN "HAROLD" HALL: Next we have Carmen "Ganz"? Just raise your hand.

CARMEN GOMEZ: Carmen Gomez.

I don't know a whole lot about this because, like Nancy, the Tisdales' neighbor is a friend of mine, called me up and said something to what me -- what? -- three days ago; otherwise, I wouldn't have known.

I'm not a tribal member, but I am Native American, and I have my paperwork to prove I'm Native American. My family fell off the rolls in 1933. And like everyone else, my family suffers from generational trauma, and we don't have a lot of money.

My biggest concern is the impact on the environment and on the wildlife. You've released studies when you put the windmills up over by Manzanita Reservation. With total disregard for that tribe over there, those windmills were put in, and they've had a really negative impact on our environment and on the people that live under them or near them.

I'm concerned about our grounds, our earth, and our wildlife, animals. This is a beautiful, beautiful countryside, and you've already got it littered way over on this end with windmills. You've completely destroyed McCain Valley which is supposed to be a state park, and I consider that a conflict of interest because the Bureau of Land Management and the BIA -- you guys are supposed to be protecting these wildlands. And, instead, you're making a financial profit from it with total disregard for the environment or the animals. You've got so many of these going around all over here already that you only said you needed a few of them back when you put those in. And now you've got this whole countryside littered with it. It's littered all over in Arizona. We have got it littered all over in other countries. And I just completely object to it. It's an eyesore.

And they're leaking. When they get so old, they leak. They break, you know. I just don't think that this is very thoughtful or very kind to the people that live out here, and I don't think it's very thoughtful or very kind to our wildlife or to our land.

DAN "HAROLD" HALL: Next, we have Mark Ostrander.

MARK OSTRANDER: Yes. I'm Mark Ostrander.

My concern is about the fire danger is going to increase in the area. We're already in a very high fire danger area.

It's proven that the more infrastructure that goes in, the probability of fire start increases. We've already had, on wind turbines in this area from Ocotillo up to here, three known wind turbine fires. We were told there was a very low probability of that happening. Already three have happened since they've gone in.

Next concern is the environmental side on the wildlife such as your birds. This is migratory bird path. They're just cutting off all the areas on their pathway to come through. We're basically going to be surrounded by wind turbines.

And the other concern is also the low frequency sound that comes off of those wind turbines.

The aesthetic. It's already just ruined our aesthetics out in this area. The views we used to have are gone, and now you're going to add more and take even more of those views away.

The other thing is those blinking red lights on top of the turbines. It's just annoying at nighttime. All you see is this red flashing haze. And when it's a little bit overcast or at night, you'll see a glare in the sky from all the lights from all the turbines that are currently there.

Also, the socioeconomic side of it. You know, property values. The fire insurance is going to go up. Property values will go down.

And also the health risks to people. There has already been case studies on a lot of people having these health issues with all kinds of different things from heart to rashes to headaches to sleep disorders. All these things are part of that.

Thank you. Oh, and cancer too.

DAN "HAROLD" HALL: Ed Tisdale.

ED TISDALE: I'm going to pass right now.

DAN "HAROLD" HALL: Donna Tisdale.

DONNA TISDALE: Donna Tisdale.

First, I want to show you where we -- our property is. We're right here, and that's a lot of stuff that's pretty close.

I told Mr. Wagner, Terra-Gen, and what we were going to fight hard; he said they were going to fight hard too. But Terra-Gen wasn't even noticed in the -- in the -- Terra-Gen was not even identified in the notice of intent, and that seems like an error.

We should have had maps here for people to pick up because I had a lot of calls. People were going to come, but they got stuck in the rain, car crashes, the roads are too muddy. So more people would have been here, and I would have picked up maps to hand out.

But the big thing is we've already got existing turbines at Kumeyaay and Tule Wind. We know what they're doing to the people.

For Kumeyaay Wind, we don't even know where to send complaints because it's hard to track down the owner. You got five different entities if you go through the Secretary of State's business search. You can't really track them down. They have agents. Where do you send your complaints?

I've done documentation. I represent --

THE REPORTER: I'm sorry, ma'am. You're speaking too fast. I can't understand you. "I represent"?

DONNA TISDALE: Three minutes is not enough to get information in on this project.

I don't even remember what I said.

But anyway, they -- we've already got information -- I represent a non-profit called Back Country Against Dumps -- Back Country Against Dumps -- and we have done -- brought in professionals from Northern California to do low-frequency noise and noise reports. We just brought them back to do another -- a round. We did them back in '13, which round.

We also documented electromagnetic interference at homes around the Kumeyaay turbines and around the Ocotillo turbines. This was before the Tule Wind turbines were there.

THE REPORTER: I'm sorry, ma'am. I can't go that fast, and I don't understand.

MAN: Wow.

DONNA TISDALE: May I have a few more minutes?

MATT VALERIO: Yeah. We'll -- we'll --

(Unreportable by stenographer.)

DONNA TISDALE: We have documented

low-frequency noise and infrasound at homes around the existing turbines at Kumeyaay Wind, Ocotillo Wind, and now Tule Wind. And the report is in the process of being finalized, and I will submit it when it's time.

We also documented electromagnetic interference, and these are homes where people have been complaining of adverse health effects. It's not dissimilar to what other communities who have turbines in their -- near their homes are also complaining about.

The main complaint is sleep deprivation and stress and anxiety because low-frequency noise does create that. Sometimes people hear the noise. Sometimes they don't hear the noise. And it's the infrasound, that they don't hear, triggers a fight-or-flight instinct within them and that creates your body to try and defend itself from something that don't really know what's trying to defend itself. That creates stress and anxiety. It can create all kinds of health effects. Heart. There's a new German study out that says infrasound is bad for the heart chamber.

So basically low-frequency noise is a form of energy, and your body is being bombarded with it by these turbines.

And I know they're going to put up 4.2-megawatt or 4-megawatt something up because

Terra-Gen already told me that when I had a meeting with them a few months ago.

So these are huge turbines. These are bigger than any other communities have. They're, like, some of the biggest. And I -- it just scares me because most people don't know what's coming. Even tribal members. I've had tribal members call me and ask me, you know, if I knew anything because they have been kept in the dark about this.

So it's a really serious issue, and we've already got issues with the existing turbines that we can't get handled. Where do we take care of that?

I wrote a letter to Ralph Goff and to Junior Cuero and to Amy Dutschke and Dale Rising, and nobody responded. I said: Who owns the turbines? Where do we send complaints? Who is responsible? And I got zero. I got no -- I got nothing.

So when people ask me, "Who do I complain to," I tell them to call here. But most people are afraid to call here or get involved because they're afraid of some kind of backlash from those who are in charge.

So -- and I don't think that's an unreasonable concern because those kind of things have happened in the past.

So -- and this is a basic connected action to

Terra-Gen's other project right next door which is the Torrey Wind Project. And together, it's going to be almost as big as Ocotillo Wind Farm except with bigger turbines. And with bigger turbines, they create more noise -- more low-frequency noise that reach even farther out. These pass through your body. They can create a vibration effect. People feel dizzy. They feel off balance. They feel anxiety. Their kids start acting out. They can't sleep.

And there's finally some reports coming out. What happened is all the money goes to the industry, to the wind companies. They don't spend any money on health effects or what's going to happen to the people that are living with them. And it's just dishonest, and it's unconscionable.

I have a lot more to say. I'll send comments.

DAN "HAROLD" HALL: Charlie Good.

CHARLIE GOOD: My name is Charles Good. I reside at 37649 Old Highway 80, Boulevard, California.

My property -- my wife says our property abuts right up against, I guess it would be, the northeast corner of the reservation.

If you want to put up these wind machines like this, you're going to destroy our property values. You know, they're not very good as it is. Thank you, Mr. SDG&E and Mr. Border Patrol. Our property values stink. They have been going steadily down. And to do this to us, I mean -- I'm going to put it pointblank: If you want to put these things up, come and give me fair market value for my property plus 25 percent.

And you should do that because if SDG&E, who I know is -- who is behind this, if they want to create an energy area up here for solar and for wind power, then buy everybody out. And they can -- you know, above market value. And then they can just have the whole thing to do whatever they want to with it because they're going to destroy us.

And as far as the -- more Powerlink going over our property, I mean, SDG&E shuts us off every time the wind blows, you know, without any regard to our safety or our comfort or our needs. So to have to create more power for downtown San Diego by Terra-Gen at our expense is totally wrong.

Thank you.

DAN "HAROLD" HALL: Next, we have Dennis Largo.

DENNIS LARGO: If I remember, I was supposed to be last or towards the last. Could I still be -- have that option of speaking last?

DAN "HAROLD" HALL: Certainly.

DENNIS LARGO: Thank you.

DAN "HAROLD" HALL: We'll move on to Clifford Caldwell then.

CLIFFORD CALDWELL: Well, my first problem is I went on the Internet to see what you had there as far as information. And for all the information I got, you could have been putting that down in Imperial Valley. I have no idea where it is in regards to my property. I have no idea where your wind turbines are going, but I do know that you're going to put something up.

So since all I'm getting from you is generalizations, I'll give you my generalizations.

My first concern is water resources. How much water are you going to be pumping? What's the estimated amount of water you're going to be using, because it affects our groundwater? Once it affects our groundwater, it's going to affect our trees. We've got a lot of oak trees. Next thing I know, my oaks trees are going to be dying. I want to know how much water they're going to be using and what is it going to be initially? What's it going to be in the long run? So that would be my first issue: the impact on the groundwater.

Then, I'll go to my next issue, intrusion of noise, vibration, and infrasound. We already have it up there. I'm north up here somewhere. And I'll be honest with you, I have no idea. Where's Ruben Wood Road? Could you tell me where Ruben Wood Road is? Or do you even know? That should be the most obvious one. Where? Point it out to me.

MATT VALERIO: It's just off the map.

CLIFFORD CALDWELL: No, it's not right off the map.

LADY: Your map stinks.

CLIFFORD CALDWELL: So, anyway, that's my next issue is, I don't think we have any idea of what we're talking about because we haven't been given any information about it, but there's all sorts of questions about the volume of the noise that we're going to be receiving, and we're right off of the reservation, and it's -- we're already getting the noise and everything now.

Are we going to have a study of the eco system to see what the effect of this is on the animals? We have a lot of animals.

I asked -- on one of the last ones, I asked, well, what's this going to do as far as the nightlife, as far as anything that's eating bugs. And you know what they said? They said, "Oh, the animals will be able to avoid it. They're fine.

Well, that's a real in-depth study, I want to tell you. But it would be nice to have someone to actually respond to some of the questions we have.

And up to now on all these other projects, we haven't gotten any responses. We haven't gotten anything in response, and we've got just about as much information as we have on this project already.

MATT VALERIO: You're close to your time.

CLIFFORD CALDWELL: Huh?

MATT VALERIO: You're close to your time.

CLIFFORD CALDWELL: Well, if you keep going, you can run my time out.

Air pollution in the area, light pollution in the area -- those are some additional things.

How about the assessment of fire risks? When my place burns down, is it bonded? Are they going to have something to cover our risk, or are they going to break this thing up into a bunch of units so when you sue somebody who started the fire that there's going to be no coverage?

MATT VALERIO: Okay. That's time.

CLIFFORD CALDWELL: Well, good. I'll keep going.

Visual impacts to the areas, cumulative effects of various projects.

That's just one project. By the time you finish, you're going to have a thousand windmills up here, and we'll never know what's going on.

But anyway, I'll save the rest of my responses and questions, but I think your actual request for public comments -- I'll be honest with you. It sucks.

You have no idea what you're talking about because you don't know where they're putting in the windmills.

So anyway, here you go.

DAN "HAROLD" HALL: If I could just interject just a second here, please. I would request that -- I know that there's a lot of strong feelings about this project on both sides, and that's something we all know.

I would just ask that people please maintain a degree of common respect for each other and just kind of --

CLIFFORD CALDWELL: I didn't show any disrespect. I'm just telling you --

MAN: These are commonsense questions he's asking. You came here totally unprepared. How can we make comments about different issues when you haven't got the basics for us like this man said?

LADY: (Unintelligible.)

MAN: Can you tell me, from the reservation line over to where the first windmill is going to go, what the distance is? Can you tell me any distances?

I know. I don't have a slip. Oh, yeah.

But what I'm saying is this gentleman was completely correct. He said one nasty word, "This sucks," and it does suck.

DAN "HAROLD" HALL: Benjamin Good, please.

BENJAMIN GOOD: I'm curious, and I'm confused.

First off, to the Campo Reservation, thank you for having us tonight. I know it's not fun to have us all out.

I've been a good neighbor to you for 16 years; you've been a good neighbor to me for 16 years.

I bought my place 17 years ago. I live right up here off of Old 80, right here, right where they split. I'm the green house and the big building. Everybody knows where I live.

Looks like you're going to change my front window. Because I bought this property 17 years ago. You guys hadn't even dreamed of doing this.

MAN: Yet.

BENJAMIN GOOD: I bought because I love your reservation. I loved what it looked like off of my window because though I'm a builder, I'm also an avid outdoorsman. Even as an outdoorsman, I want my outdoors left alone. Only to be for the outdoors this far out.

My question for you is, are you going to put 586-feet-tall poles, just like they did, west of the Five when we built down there? We gotta prove that we're not inhibiting somebody's beautiful view?

You are going to steal my view because when I look out my window now at night, I'm going to have red lights, "Pop, pop, pop, pop, pop."

DAN "HAROLD" HALL: Excuse me. I would ask if you could address the table and the stenographer.

BENJAMIN GOOD: I can do that.

So from your house if your door was right there, would you be okay with somebody coming 16 years -- 17 years after you started your project, you built equity in a home that you carved out of the brush, and somebody is going to change what you started?

I don't think that's fair. And I know I'm not the only person in that spot. Campo has been good to me; I've been good to Campo. I've bought products on the Reservation. We've commerced. We've been good.

But when you start going down this road, you have to compensate other people's capital investment. I'm a free-enterprise person. I am all about free markets. I am all about free enterprise. I'm all about getting to do with your land what you feel best for your land, but you can't do it at my cost, at my expense.

You're going to take a property that I purchased, I've been building my family on for the last 17 years, and you're going to put it in the toilet.

And you, sir, would not be happy if somebody did that to your front yard. That's my front yard that you're doing that to.

DAN "HAROLD" HALL: One minute.

BENJAMIN GOOD: You said three minutes. I have one more. Okay.

So that being said, I need you, if you're going to change my world, to give me an option to change my world, not just tell me what I have to live with.

What are my options? What are you going to do for the people of Campo? For the people that are outside this reservation that have been good neighbors to the Campo Reservation?

What are you going to do for those people who are going to see no dimes from this except for loss?

That is not win-win; that is win-lose. Those outside that circle will lose; those inside that circle will win.

I'm a win-win guy. We all need to win. Your land, all about it.

Don't ruin mine.

DAN "HAROLD" HALL: Thank you.

Michelle Cuero?

MICHELLE CUERO: Can you put me last on the very bottom, or am I last?

LADY: Everybody wants to be last.

DAN "HAROLD" HALL: Everybody wants to be last. There are two cards left.

MICHELLE CUERO: Okay. I'll just talk.

Hi. I'm Michelle Cuero, a Campo member from here, and I'm the Campo member from here, and I didn't know about this meeting tonight. I didn't know that we were giving up all of our land for a measly amount of money. I didn't know that. I didn't know that they were going to come tear up all of our trees and dig up our roads and fence our land off.

I'm on enrollment committee. We may be enrolling 100 extra members. We don't -- not going to have nowhere to live now, because all these turbines, you can't live under them.

I'm worried for my tribe. I don't -- I'm against this project, and I will do everything I can to stop it. Thank you.

DAN "HAROLD" HALL: Dennis Largo.

DENNIS LARGO: Thank you.

I want to thank everybody for being here, and, white people, thank you for being here, but the people -- the person I really would like to address to is the fellow on the -- I don't need that.

The person that I'd really like to talk to is the person from the BIA.

That's you, right?

MAN: (No audible response.)

DENNIS LARGO: You in the gray hair and the black coat? You.

You really want -- you really -- the person that I really want to talk to you is because of the way that they went about it, this vote.

We were told that evening that we were not going to have a major vote on this project here, and it turned out we did. And it turned out that there wasn't that many -- all the people that were there were the people that wanted it because they, like you people, didn't know nothing about it till the very last minute.

Now we are suffering the very same thing. I wasn't told and -- I wasn't told about this meeting until about eight hours ago, I was told about it, and I wanted to be here because I consider myself the main opponent of this project. I always have been.

But the reason why I really don't want this project, because I'm seeing our reservation rights, our -- the way of our customs and traditions totally violated through about four people. Four people -- only four people that I have figured out living here in ten years are going to benefit by this project.

You see that crappy-looking thing you got there? We got the same crappy-looking thing. We got it. And it ain't worth a shit. I'll say it, really, it ain't worth a damn. Okay?

So in my power and any kind of power I got using white people, serra book [phonetic], anything, death maybe, it ain't going to happen. It is not going to happen. Okay, white people? I promise you that. It ain't going to happen.

Thank you.

DAN "HAROLD" HALL: Were there any more commenters that provided cards? Is that it?

LORRIE OSTRANDER: Sir, I didn't put a card in, but I would like to say something.

DAN "HAROLD" HALL: If you would please just fill out --

LORRIE OSTRANDER: I'll put a card in after I --

DAN "HAROLD" HALL: Yes.

LORRIE OSTRANDER: Okay. I'm Lorrie Ostrander. I live at 43577 Old Highway 80 in Jacumba.

And whether you realize it or not, the ones that -- the turbines that are on the hillside, the blinking lights and everything -- I've lived in this area for 29 years -- 29 years. We have pictures of how this beautiful backcountry looked. I used to be able to see the sun rise or the moon at night over where the Mexican hillside is.

It's not a beautiful sight anymore. The sad thing is when the first turbines went in with all the blasting between SDG&E and all the turbines, we had wildlife in my backyard. We had never seen a puma. We had a hairless coyote from the stress. We lost golden eagles. In one of the areas where we live at Bankhead Springs, there was a pair. I lost two ravens. And we all know that when they mate, they mate for life, and they lost one mate. They died. I buried that one on my property. I had a timber wolf who died of brain cancer after the turbines went in.

Our water, our well, is dropping like anything with all the projects that are coming out here.

Folks, do you remember when Arnold Schwarzenegger came out here? And we did a little protest. It was a nice one, but we were letting him know we didn't want it.

DAN "HAROLD" HALL: One minute.

LORRIE OSTRANDER: Okay. Real quick.

What was our governor's comment, and Arnold? Crush them. We're going to make it a back area of all the envi- -- the turbines, the wind, the solar systems, but crush them.

Thank you. Just a reminder of what was said years ago.

DAN "HAROLD" HALL: Thank you. So if that's the remainder of the comments, that concludes our public hearing on the proposed Campo Wind Energy Project this evening. I appreciate your attendance and your comments.

Again, if you would like to provide written comments, please do so and get those to us by December 21.

(Meeting adjourned at 6:53 PM.)

REPORTER'S CERTIFICATE

I, Veronica S. Thompson, Certified Shorthand Reporter for the State of California, do hereby certify:

That the foregoing proceedings were reported stenographically by me and were transcribed through computerized transcription by me and that the foregoing is a true record of the proceedings taken at that time

Witness my hand dated December 16, 2018.

____

Veronica S. Thompson
CSR 6056, RPR, CRR