BEFORE
THE OHIO POWER SITING BOARD

In the Matter of the Application of **Seneca Wind, LLC** for a Certificate to Site Wind-Powered Electric Generation Facilities in Seneca County, Ohio	))))	Case No. 18-0488-EL-BGN

PETITION TO INTERVENE OF SENECA COUNTY RESIDENTS

Pursuant to R.C. 4906.08(A)(3) and O.A.C. 4906-2-12, Seneca County residents Chris & Jena Lyn Aicholz, Anthony & Tamra Andrews, Nate Blaser, Justin & Tori Brenner, Colton & Haley Carrick, Don & Wendy Carrick, Dave Clark, Tim Cornett, James Dillingham, Charles & Jodi Gaietto, Steve Gitcheff, David & Joann Graham, Charles Groth, John & Terri Hampshire, Debra & Duane Hay, Joseph & Diane Hudok, Bob & Sandy Kennard, Randy Kuhn, Mark & Donna Lambert, Brandon & Danette Martin, Michael & Christal McCoy, Jeff & Marnie Miller, Nate & Steph Miller, Richard & Gail Miller, Tom & Beth Nahm, Jeffrey & Evelyn Phillips, Jason & Shanna Price, Eric Reis, Gregory & Janeen Smith, Tom & Shelley Smith, Chris & Kristie Theis, Mike & Carol Theis, Don & Kim Thompson, Jacob & Ashley Tidaback, Robert & Judith Watson, Rod & Nancy Watson, and Bonnie Wright (the "Local Residents") hereby petition the Ohio Power Siting Board for an order granting their intervention as parties in this proceeding.

This Petition to Intervene is supported by the Memorandum in Support set forth below.

Respectfully submitted,

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MEMORANDUM IN SUPPORT OF PETITION TO INTERVENE

A. INTRODUCTION

On July 16, 2018, Seneca Wind, LLC ("Applicant") filed its application (the "Application") for a certificate of environmental compatibility and public need to construct a 200MW, 85-turbine wind-powered electric generation facility (the "Project") in Seneca County. On October 15, 2018, the Board entered a notice on the docket deeming the Application to be complete and directing Applicant to serve the complete Application pursuant to O.A.C. 4906-3-07. Applicant served the complete Application, and delivered notice to local public libraries, on or about October 16, 2018.

The Local Residents are long-time residents of Seneca County. The vast majority of the Local Residents own and live in homes within the footprint of the Project. Long-time Seneca County residents Debra & Duane Hay, Randy Kuhn, Jacob & Ashley Tidaback, and Robert & Judith Watson own parcels within the Project footprint (the Tidabacks intend to build their new home within the Project footprint).[1] Recently, in *In the Matter of the Application of Republic Wind*, OPSB Case No. 17-2295-EL-BGN, the Board determined that the standard for determining whether local residents (Seneca County residents in that case) will be permitted to intervene in a wind turbine project certification proceeding is whether the local residents live

[1] The addresses of the Local Residents' homes and property within the Project footprint are set forth on Exhibit 1 attached hereto.

within the proposed project area. *See* Exhibit 2 attached hereto, August 21, 2018 Entry in the *Republic Wind* case, at ¶20:

> * * * The Board has granted petitions to intervene when the petitioner can demonstrate an individual, direct interest in the outcome of a proceeding. *In re Black Fork Wind LLC,* Case No. 09-546-EL-BGN, Entry (Mar. 2, 2010) (where the Board granted intervention to individuals with property that abuts directly with the proposed project site.). In this case, this nexus has been established by [identified Seneca County residents], ***all of whom reside inside the project area.*** Additionally, this nexus has been established by [identified Seneca County residents] ***stemming from the fact that their property abuts the project area, which results in them being directly impacted by the proposed project.*** Therefore, the motions to intervene shall be granted for these individuals. (Emphasis added).

The Local Residents are entitled to intervene in this proceeding under this standard.

Moreover, the Local Residents possess direct, personal interests that they need to protect in this proceeding:

- Applicant's Project violates the wind turbine setback requirements of R.C. 4906.20, invading the zone of protection afforded to the Local Residents and other non-participating residents under that statute.
- The Local Residents will be subjected to continual noise emitted by Applicant's wind turbines at levels that exceed World Health Organization (WHO) health standards for nighttime noise.
- Non-participating residents will be subjected to shadow flicker in their homes at levels that exceed the regulatory maximum of 30 hours per year.
- The Local Residents watch, enjoin and benefit from the presence of birds, bats, and bald eagles in Seneca County that will be harmed and killed by Applicant's wind turbines.

- The Local Residents consume ground water that may be contaminated by Applicant's excavations at 85 turbine sites. Applicant has sited its turbines in a karst-ridden area that the Ohio EPA has designated as a "Drinking Water Source Protection Area" for "Community Public Water Systems using Ground Water with a High Susceptibility to Contamination and Water Quality Impacts." *See* Exhibit 3 attached hereto.
- The Local Residents enjoy beautiful viewsheds from their homes that will be marred by Applicants 650+ foot turbines.
- Applicant's excavations at 85 turbine sites may destroy or damage significant cultural artifacts buried in Seneca County.
- Rather than helping to reduce global warming, Applicant's wind turbine Project will contribute to global warming. A recent study from scientists at Harvard University establishes that for the next 100 years, the operation of wind turbines will actually increase global warming. *See* Exhibit 4.
- The numerous adverse effects of Applicant's wind turbines will diminish the value of the Local Residents' property.

The Local Residents seek to intervene in this proceeding to protect these personal interests that will be detrimentally affected if Applicant is permitted to construct its Project in close proximity to their homes, as Applicant proposes in its Application. They are entitled to intervene in this proceeding.

B. THE LOCAL RESIDENTS' INTERESTS TO BE PROTECTED

1. The Project Violates The Mandatory Setbacks Of R.C. 4906.20

R.C. 4906.20 provides that Applicant's industrial wind turbines must be sited no closer to the property lines of the nearest non-participating property owners than 1,125 feet (in horizontal distance) from the tip of the turbine's nearest blade at 90 degrees to the property line (*i.e*, a horizontal distance of 1,125 feet plus one-half the rotor diameter of the turbine):

> * * * That minimum [setback for a wind turbine] shall be . . . at least one thousand one hundred twenty-five feet in horizontal distance from the tip of the turbine's nearest blade at ninety degrees to [the] property line of the nearest adjacent property at the time of the certification application.

See also O.A.C. 4906-4-08(C)(2)(b).

The R.C. 4906.20 property line setbacks for Applicant's proposed turbine models are:

Turbine Model	One-Half Rotor Diameter	Setback (1,125 ft. + 1/2 R-D)
GE 2.3-116	190.5 feet	1,315.5 feet
GE 2.5-127	208.5 feet	1,335.5 feet
SG 2.7-129	212.75 feet	1,337.75 feet

As currently sited by Applicant, numerous turbines in its Project violate R.C. 4906.20's non-participating property line setback, including with respect to properties owned by some of the Local Residents. For instance, Applicant currently sites its turbine #85 less than 740 feet east of the property line of Local Residents Greg & Janeen Smith. *See* Exhibit 5 (this is a print-out from an interactive map on Applicant's website; the green "balloon" is on the Smiths' east property line; turbine #85 is 0.14 miles (739 feet) east of the property line). Indeed, Applicant acknowledges that its turbines are sited as close as 735 feet from non-participating property lines, and the average distance of its turbines from non-participating property lines is only 1,180 feet -- at least 135 feet short of the statutory minimum. Application at 94. The Board cannot permit Applicant to site its turbines in violation of R.C. 4906.20.

2. Applicant's Turbines Will Produce Noise At Non-Participating Residences In Excess of the World Health Organization's 2009 40 dBA Threshold For Adverse Health Effects

The area of Seneca County in which Applicant proposes to construct its Project, in close proximity to the Local Residents' homes, is particularly inappropriate for such a noisy and disruptive development. The proposed Project area is much more densely populated than locations often selected for the siting of wind turbine projects of this size (there are 2,902 residences within 1 mile of the project). As a result, when one factors in the 3 dBA margin of error in Applicant's noise modeling calculations -- and the error may be larger for Applicant's particular calculations (*see* ISO International Standard 9613-2, Table 5, the methodology for the noise calculations used by Applicant) -- at least 1416 non-participating residences and businesses (over 25% of the local properties modeled) may be subjected to continual noise from Applicant's wind turbines at volumes exceeding the World Health Organization's ("WHO") 2009 40 dBA threshold for nighttime noise that causes deleterious health effects.[2] The homes of many of the Local Residents are included in that group. In fact, the number of residences and businesses that would be subjected to noise in excess of the WHO 40 dBA health standard will be substantially higher than 1,416, as Applicant artificially lowers its noise emissions calculations (showing numerous additional violations) by stating it will use some unidentified "noise-reduction technology" for 12 unidentified turbine locations because those locations exacerbate noise

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[2] The WHO also promulgated "Environmental Noise Guidelines for the European Region" this year. However, the WHO emphasized that its 2018 publication does not supersede the WHO 2009 nighttime noise guidelines. Also, the 2018 publication identifies a 45 dBL_{den} (annual average for day, evening, and night) sound level for wind turbine noise -- but finds that "a 10 dBA penalty [is to be] added to the average sound level in the night," *i.e.*, that the average nighttime (11 p.m. to 7 a.m.) noise, dBL_{night}, should be no greater than approximately 38.3 dBL_{eq} (the measure used in the 2009 guidelines).

exceedances. September Updated Acoustic Assessment at 13. Applicant gives no explanation to justify its artificial manipulation of its calculations of noise exceedances. Thus, in the real world, vast numbers of non-participating Seneca County residents will be subjected to the risk of incurring the adverse health effects -- loss of sleep, fatigue, headaches, irritability, and the like [3] -- typically caused by such continual, excessive wind turbine noise.

Furthermore, Applicant asserts that its calculations establish an extraordinarily-high 46 dBA average nighttime noise level (L_{eq}) in rural Seneca County. Application at 67. Applicant then adds 5 dBA to its inflated 46 dBA calculation of average ambient nighttime noise in rural Seneca County to arrive at a purportedly "acceptable" noise limit of 51L_{eq} at the noise-sensitive residences of non-participating Seneca County residents.[4] *Id.* However, the Local Residents' noise expert will establish that Applicant's extraordinarily-inflated 51 dBA noise limit is fatally flawed for numerous reasons. First, it appears that Applicant's ambient noise monitors were placed closer to roads and intersections than many of the homes of Seneca County's residents are located. Clearly, measurements taken closer to roads than local residences are situated will result in non-representative readings with noise "spikes," which in turn inflate the calculation of nighttime ambient noise averages.

Second, Applicant's calculation of a 46 dBA average nighttime ambient noise level is further inflated by its apparent failure to screen out wind noise picked up by its noise monitors.

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[3] The adverse health effects commonly experienced by people subjected to excessive wind turbine noise include loss of sleep, sleep interruption, fatigue, headaches, dizziness, irritability, anxiety, and stress. This cluster of common adverse health effects has been labeled "Wind Turbine Syndrome." *See* Wind Turbine Syndrome, Dr. Nina Pierpont (K-Selected Books 2009) at 194 (". . . [T]he definitive result of my report is that wind turbines cause the symptoms of Wind Turbine Syndrome (WTS).").

[4] Applicant asserts that "Project-only sound levels will not exceed 51 dba at non-participating residences." Application at 76. That assertion is wrong. Just within the minimum 3 dBA margin of error of Applicant's calculations (the error way be greater), Applicant's already-inflated 51 dBA mark may be exceeded at no less than sixty (60) non-participating residences.

This is a fundamental error in the proper measurement of ambient noise levels. Interfering wind noise should be filtered out of ambient noise measurements to obtain valid measurements. *See* ANSI/ASA American National Standard S12.100-2014, *Methods to Define and Measure the Residual Sound in Protected Natural and Quiet Residential Areas* at viii.

Third, Applicant's use of an "average" (L_{eq}) noise measurement -- reflecting long periods of little noise punctuated by momentary spikes of louder noise -- does not accurately reflect how quiet the rural Seneca County project area actually is at night. The Seneca County nighttime is not a constant, raucous clamor of 46 dBA (few would be able to sleep) -- but the quiet Seneca County nighttime would be a constant clamor of 51 dBA noise if Applicant's turbines were permitted to run all night long. The true measure of the Seneca County "background" or "residual" nighttime noise -- the noise measured during the long night periods when momentary noise spikes are not occurring -- is the L_{90} noise measurement.[5] That residual nighttime noise level is quite low. In fact, in the *Republic Wind* case before the Board (Case No. 17-2295-EL-BGN), Republic Wind's noise expert acknowledged that the residual nighttime noise in Seneca County (just north of, and contiguous to Applicant's Project area) averages 23 dBA. As Republic Wind stated in its application:

> The relatively larger difference between equivalent continuous levels (L_{eq}) and lower tenth percentile levels (L_{90}) at most of the [monitoring] sites indicate that the soundscapes are dominated by ***transient events*** resulting from human activity.
> . . .
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> * * *

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5 American National Standards Institute/Acoustical Society of America American National Standard S12.100-2014: ". . . The main purpose of this standard is to develop procedures to estimate the residual sound levels in an area where these levels are used to evaluate the effects of a noise source, with two examples being ***wind turbine noise in quiet rural areas*** and transportation noise in U.S. National Parks and wilderness areas." *Id.* at viii (Emphasis added). "Residual sound" is defined as "at a specific time, the all-encompassing sound, being usually a composite of sound from many sources from many directions, near and far, remaining at a given position in a given situation when all uniquely identifiable discrete sound sources are eliminated, rendered insignificant, or otherwise not included. NOTE: ***Residual sound may be approximated by the percentile sound level exceeded during 90-95 percent of the measurement period.***" *Id.* at Section 3.2 (Emphasis added).

> . . . These [L_{eq}] levels were higher than the L_{90} for the same period, which indicates that the maximum sound levels over the period ***were brief***, but relatively high. . . . The overall L_{90} [for the "North Boundary" monitor], ***as an indication of the residual sound level***, was lower: ***27 dBA overall, 28 dBA daytime, 25 dBA nighttime***. (Emphasis added).

See Exhibit 6 (Republic Wind Application, Exhibit H, Noise Impact Assessment, at 19-20). This very low nighttime noise level is what would be expected for a rural area like Seneca County if one uses appropriate sound measurement methodologies. Nighttime residual sound levels in rural areas like Seneca County that are measured using the accepted methods of ANSI/ASA American National Standards S12.9 and S12.100 are routinely under 30 dBA (L_{90}).

3. The Project Will Subject Non-Participating Residents to Shadow Flicker in Excess of the 30 Hours Per Year Limit

Large industrial wind turbines like Applicant's cause "shadow flicker" on and within nearby residences -- the strobing of shadows across the residence as the blades of the turbines rotate through sunlight that shines on the residence. This strobing of light and shadows on a residence can be extremely annoying, causing anxiety, irritability, and headaches to residents. As a result, wind turbines are not permitted to subject non-participating residences to any more than 30 hours of shadow flicker per year to protect occupants from adverse health effects. O.A.C. 4906-04-09(H)(1). *See also*, Wind Energy & Wind Park Siting and Zoning Best Practices and Guidance for States (National Association of Regulatory Utility Commissioners, January 2012) at 31.

Applicant acknowledges the 30-hour limit for shadow flicker imposed upon occupied residences. Application at 98. Yet Applicant's own Shadow Flicker Report (Application, Appendix J) reveals that, in a worst case scenario, at least twenty-six (27) non-participating residences may be subjected to shadow flicker from Applicant's turbines for 30 hours or longer -- with non-participating residences being subjected to up to more than sixty-two (62) hours of shadow flicker, in violation of Ohio law. September 2018 Updated Shadow Flicker Analysis at Table 1. Applicant cannot be permitted to impose these health-threatening levels of shadow flicker upon the non-participating residents of Seneca County.

4. Applicant's Turbines Will Kill Migratory Birds, Bald Eagles, and Bats

Applicant's industrial size wind turbines will kill migratory birds. The Local Residents will proffer the testimony of an avian expert to establish that Seneca County is located in the midst of avian nocturnal migratory pathways that are populated with hundreds of thousands, if not millions, of birds each spring and fall. Nearly all song bird (passerine) migration occurs at night. Yet Applicant has performed no avian nocturnal migration radar studies. None -- despite Applicant's admission that "***[t]he majority of the fatalities at wind turbines documented [i]n the Midwestern and Eastern regions of the U.S. have been nocturnal migrants***." Application at 147 (Emphasis added). Instead, Applicant conducted a diurnal study (observing by sight and sound the local, daylight activity of birds), and by those local daytime observations attempts to guess what might happen during nocturnal migrations. In short, Applicant has no clue as to the likelihood that its proposed Project will kill significant numbers of migratory birds during their annual spring and fall nocturnal migrations. Applicant cannot even begin to make its required showing of "the probable environmental impact" of its Project (R.C. 4906.10(A)(2)) on migrating birds, much less show that its siting of the Project "represents the minimum adverse environmental impact" to the vast numbers of birds migrating through Seneca County. *See* R.C. 4906.10(A)(3).

In addition, there may be fifteen (15) or more active bald eagles nests in Seneca County -- placing those protected birds at risk of death in violation of the federal Bald and Golden Eagle Protection Act (16 U.S.C. 668 *et seq.*). *See* Exhibit 7 (a current map of the bald eagle nests in

Seneca County). Applicant's spring 2017 survey reports only three (3) active bald eagles nests. Today, there appear to be many more bald eagles resident in the Project area, putting bald eagles at much greater risk of death from Applicant's turbines.

Finally, Seneca County is home to numerous bat species that would be killed by Applicant's proposed turbines. Applicant's own bat studies confirm that the Project area is populated with an endangered bat species, the Indiana bat. Application at 119 ("It is anticipated that mammal species likely to occur in the [Project] area include . . . [the] Indiana bat. . . ."). Applicant's proposed Project puts these endangered bats at risk of death in violation of the federal Endangered Species Act (16 U.S.C. 1531 *et seq.*).

5. **Applicant's Construction of Its Project in an Ohio EPA-Designated "Drinking Water Source Protection Area" Creates an Unacceptable Risk That the Project Will Contaminate the Local Residents' Drinking Water**

The Ohio EPA has designated the area of Seneca County in which Applicant plans to build its project as a "Drinking Water Protection Area" where the residents obtain their drinking water from ground water that is highly-susceptible to contamination. *See* Exhibit 3. The Local Residents' shallow-well-based drinking water is highly susceptible to contamination because the area in which Applicant has sited its Project constitutes Ohio's largest karst area, known as the "Bellevue-Castalia Karst Plain" (the "Seneca Karst Plain").

The Seneca Karst Plain is riddled with underground caverns, caves, and voids that have been created in limestone, dolomite, and gypsum by reactions of these minerals with ground water. The Seneca Karst Plain contains enormous underground voids (some larger than 270 acres) and massive underground passageways through which water flows quickly, in large volumes. Thus, if any one of Applicant's 85 excavations for its proposed turbines were to contaminate the Seneca County ground water -- which is high-susceptibly to contamination, as the ground water is close to the surface and large sink holes and subsidences commonly result from even shallow excavations in the soft underlying gypsum and limestone -- that contamination will travel quickly, and far, throughout the County's ground water. Applicant's Project simply is sited in the wrong place. It creates unacceptable and unnecessary risks to the drinking water of Seneca County's residents.

6. **Applicant's Construction of Eighty-Five 650+ Foot Wind Turbines (Taller Than Any Building In the City of Columbus) Will Forever Destroy The Beautiful Rural Viewsheds of Seneca County**

Applicant's construction of 85 enormous (up to 650 feet) turbines would be a blight on the rural, residential viewsheds of Seneca County. Those turbines are taller than any building in the City of Columbus, and there would be 85 of them. Local Residents Greg & Janeen Smith alone would have 18 such monstrous structures within one mile of their home. Moreover, many of the Local Residents have chosen to live their entire lives in rural Seneca County for the very purpose of avoiding offensive and invasive industrial developments such as Applicant's Project. Applicant should not be permitted to use the Board's certification process to destroy the Local Residents' otherwise peaceful rural homesteads.

7. **There Is No Environmental Benefit to Applicant's Wind Turbines. They Will Contribute to Global Warming, Rather Than Reduce It**

Applicant asserts that its proposed Project will produce "clean, renewable energy." Application at 1. The direct adverse (and uncompensated for) effects of wind turbines set forth above refutes the naïve assertion that wind-generated electricity is "clean." It is anything but clean. No electric generation technology is clean. But a recent study published by two professors at Harvard University indicates that wind-generated electricity is even less clean than generally has been touted by its proponents. The proponents of wind energy have long proclaimed that wind-generation must attain an ever-increasing share of our nation's electric generation market in order to combat greenhouse gasses and global warming. But it turns out that wind energy facilities actually contribute to global warming, rather than reduce it, and will continue to do so for at least the next 100 years. *See* Exhibit 4.

8. All of the Adverse Affects of Applicant's 85 Wind Turbines Will Reduce the Value of the Local Residents' Homes

All of the foregoing detrimental impacts of Applicant's Project will diminish the value of the Local Residents' homes. By constructing its Project, Applicant would effect a "taking" of the Local Residents' property without compensation.

In short, the Local Residents possess numerous legally-protectable interests that will be adversely affected by Applicant's proposed Project. The Local Residents are entitled to intervene in this proceeding pursuant to R.C. 4906.08(A)(3) and O.A.C. 4906-2-12.

C. INTERVENTION STANDARD

The Local Residents meet all requirements for intervention in this proceeding as set forth in R.C. 4903.08(A) and O.A.C. 4906-2-12(B)(1). The Board may consider the following when determining petitions to intervene:

(a) The nature and extent of the person's interest;

(b) The extent to which the person's interest is represented by existing parties;

(c) The person's potential contribution to a just and expeditious resolution of the issues involved in the proceeding; and

(d) Whether granting the requested intervention would unduly delay the proceeding or unjustly prejudice an existing party.

O.A.C. 4906-2-12(B)(1). See also *In the Matter of the Application of Clean Energy Future—Lordstown, LLC,* No. 14-2322-EL-BGN, slip op. at 2, ¶5 (Ohio Power Siting Bd. July 28, 2015) (setting forth factors the Board considers in resolving motions to intervene); *In the Matter of the*

Application of Columbus Southern Power Co., No. 01-2153-EL-BTX, slip op. at 3, ¶8 (Ohio Power Siting Bd. Jan. 29, 2004) (same).

The Ohio Supreme Court has interpreted this rule as providing that "***[a]ll*** interested parties may intervene in [Board] proceedings upon a showing of good cause." *State, ex rel. Ohio Edison Co. v. Parrott,* 73 Ohio St.3d 705, 708 (1995) (citation omitted) (emphasis added). Accordingly, the Board has granted numerous petitions to intervene filed by property owners whose property would be affected by a proposed project. *See In the Matter of the Application of Republic Wind LLC, supra*; *In the Matter of the Application of Buckeye Wind LLC,* No. 13-360-EL-BGA, slip op. at 5-6, ¶¶12-14 (Ohio Power Siting Bd. Nov. 21, 2013) (granting motion of proposed intervenors who claimed that the wind project would have "potential impacts" on "their residences, land, roads, and community").[6]

D. THE LOCAL RESIDENTS ARE ENTITLED TO INTERVENE

1. The Local Residents Have Real And Substantial Interests In This Proceeding

The Local Residents are residents of Seneca County who reside or own property in the Project area. Under the Board's enunciated standard for local residents to intervene in wind turbine project cases, they are entitled to intervene in this case. Moreover, as set forth above, they possess numerous personal interests that will be directly affected by Applicant's proposed Project. They have delineated the important interests they are entitled to protect in this proceeding.

6 See also *In the Matter of the Application of Champaign Wind, LLC,* No. 12-160-EL-BGN, slip op. 3-6, ¶¶19-23, 25 (Ohio Power Siting Bd. Aug. 2, 2012) (granting motion to intervene of "property owners who own real estate and reside within the footprint of the" wind turbine project and who "have a direct and substantial interest in [the] matter, in light of the potential visual, aesthetic, safety, and nuisance impacts of the wind project on their residences, land, and community"); *In the Matter of the Application of American Transmission Systems, Inc.,* No. 12-1636-EL-BTX, slip op. at 1-2, ¶¶3-6 (Ohio Power Siting Bd. May 21, 2014) (granting motions to intervene of property owner along the possible alternate route of a proposed transmission line).

2. The Local Residents' Interests Are Not Already Adequately Represented

The Local Residents' interests are not adequately represented by the existing parties in this case. No existing party to this action has the same personal interest as the Residents in: (1) enforcing R.C. 4906.20's setbacks with respect to the Project; (2) protecting the Local Residents and other non-participating Seneca County residents from the Project's excessive wind turbine noise to which they will be subjected in their homes; (3) protecting non-participating Seneca County residents from the excessive shadow flicker that the Project will visit upon their homes; (4) protecting birds, bald eagles, and bats in Seneca County that the Local Residents regularly watch and enjoy; (5) protecting the drinking water of Seneca County residents from the contamination that is likely to be caused by Applicant's excavations at 85 turbine sites; (6) preserving the beautiful rural viewsheds that the Local Residents enjoy from their long-established homesteads; (7) protecting Seneca County's cultural resources; and (8) protecting the Local Residents' economic interests and preventing diminution in the value of their homes. The Local Residents would be the only parties to this proceeding who actually reside in Seneca County and the only parties who would be required to live every day of their lives surrounded by Applicant's 650-foot turbines. Absent intervention, the Local Residents will have no effective means to protect their vital interests in this proceeding.

3. The Local Residents Will Contribute To A Just And Expeditious Resolution Of Issues

The Local Residents' intervention will contribute to a just and expeditious resolution of the issues in this proceeding. They have unique, independent perspectives on the issues before the Board in this case. They possess direct, personal interests that only they, "on the ground" in Seneca County, can adequately protect. Their participation is crucial to an informed, balanced, and fair disposition of the interests of all parties who will be affected by the Board's findings and determinations in this proceeding.[7] They agree to be bound by all of the Board's determinations in this case.

4. The Local Residents' Intervention Will Neither Delay This Proceeding Nor Prejudice Parties

The Local Residents' intervention will neither unduly delay this proceeding nor unjustly prejudice any existing party. They will abide by all Board deadlines and present their evidence in a clear and concise manner.

For the foregoing reasons, the Local Residents request the Board to grant this Petition to Intervene.

Respectfully submitted,

/s/ John F. Stock

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[7] It is a cornerstone principle of American jurisprudence that an independent tribunal can best make an informed decision when interested parties on both sides of a dispute present their positions for adjudication. *See Greenlaw v. United States*, 554 U.S. 237 at 243 (2008) ("In our adversary system, in both civil and criminal cases . . . we follow the principle of party presentation. That is, we rely on the parties to frame the issues for decision and assign courts the role of neutral arbiter of matters the parties present."); *Laurent v. Laurent*, Third Dist. App. No. 92-LW-4677 (Ohio 3rd Dist.), 1992 WL 293061 (October 16, 1992) at *3 (". . . The adversarial system works best when there are two adversaries. Trial courts and courts of appeal alike benefit from the informed argument of counsel.").

CERTIFICATE OF SERVICE

The Ohio Power Siting Board's e-filing system will electronically serve notice of the filing of this document on the parties referenced in the service list of the docket card who have electronically subscribed to this case. In addition, the undersigned certifies that a copy of the foregoing document also is being served upon the persons below via electronic mail this 13th day of November, 2018.

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17. Bob and Sandy Kennard
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18. Randy Kuhn
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    15722 E. TR 104
    Attica, Ohio 44807

21. Michael D. and Christal A. McCoy
    6033 E. Twp. Rd. 58

Bloomville, Ohio 44818

22. Jeff & Marnie Miller
    7124 East Twp. Rd. 163
    Bloomville, OH 44818

23. Nate & Steph Miller
    13531 East County Road 36
    Republic, Ohio 44867

24. Richard & Gail Miller
    14411 U.S. Rte. 224
    Attica, Ohio 44807

25. Tom & Beth Nahm
    4997 S. Township Rd. 159
    Tiffin, Ohio 44883

26. Jeffrey & Evelyn Phillips
    4248 S. Twp. Rd. 197
    Attica, Ohio 44807

27. Jason & Shanna Price
    6438 S. Twp. Rd. 159
    Tiffin, Ohio 44883

28. Eric Reis
    3310 S. SR 67
    Tiffin, Ohio 44883

29. Gregory A. and Janeen A. Smith
    5139 E. Twp. Rd. 44
    Bloomville, Ohio 44818

30. Tom & Shelley Smith
    11376 East Township Road 8
    Republic, Ohio 44867

31. Chris & Kristie Theis
    4555 E. Township Rd. 58
    Bloomville, Ohio 44818

32. Mike & Carol Theis
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Republic, Ohio 44867

33. Don & Kim Thompson
12720 CR 36
Republic, Ohio 44867

34. Jacob T. and Ashley R. Tidaback
5465 S. Twp. Rd. 173
Bloomville, Ohio 44818

35. Robert & Judith Watson
101 N. County Rd. 27
Republic, Ohio 44867

36. Rod & Nancy Watson
1100 East Township Road 77
Republic, Ohio 44867

37. Bonnie Wright
694 South Township Road 79
Republic, Ohio 44867

THE OHIO POWER SITING BOARD

IN THE MATTER OF THE APPLICATION OF REPUBLIC WIND, LLC FOR A CERTIFICATE TO SITE WIND-POWERED ELECTRIC GENERATION FACILITIES IN SENECA AND SANDUSKY COUNTIES, OHIO.	CASE NO. 17-2295-EL-BGN

ENTRY

Entered in the Journal on August 21, 2018

I. SUMMARY

{¶ 1} The administrative law judge grants the motions to intervene filed by Duane and Deb Hay, Gary and Dawn Hoepf, Greg and Laura Jess, Mike and Tiffany Kessler, Kevin and Jennifer Oney, Tom and Lori Scheele, David P. Hoover, Jeffrey A. Hoover, Doug and Jennifer Myers, Chris and Danielle Zeman, the Ohio Farm Bureau Federation, Adams Township, Pleasant Township, Reed Township, Scipio Township, and York Township, but denies intervention to Carol Burkholder, Rita and Jerry Cantu, Duane Robinson, and John and Lisa Wilson.

II. DISCUSSION

A. *Procedural History*

{¶ 2} Republic Wind, LLC (Republic or Applicant) is a person as defined in R.C. 4906.01.

{¶ 3} R.C. 4906.04 provides that no person shall construct a major utility facility in the state without obtaining a certificate for the facility from the Ohio Power Siting Board (Board).

{¶ 4} On November 13, 2017, Republic filed a pre-application notification letter with the Board regarding its proposed windfarm with up to 200 megawatt (MW) electric generating capacity in Seneca and Sandusky counties, Ohio. According to the letter, the proposed site will consist of approximately 35,000 acres of leased land in Adams, Pleasant,

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in the proceeding; the legal position advanced by the prospective intervenor and its probable relation to the merits of the case; and whether the intervention by the prospective intervenor will unduly delay the proceeding or unjustly prejudice an existing party. Pursuant to Ohio Adm.Code 4906-2-12(B), the ALJ may grant an untimely filed petition to intervene only upon a showing of extraordinary circumstances and good cause, in addition to the petitioner agreeing to be bound by matters previously decided in the proceeding and providing a statement of good cause for failing to timely file its petition.

1. SENECA COUNTY RESIDENTS' MOTION TO INTEVENE

{¶ 9} On June 19, 2018, as amended on June 22, 2018, the following Seneca County residents filed a motion to intervene in this proceeding: Chris and Danielle Zeman, Carol Burkholder, Duane and Deb Hay, Gary and Dawn Hoepf, David Hoover, Jeff Hoover, Greg and Laura Jess, Mike and Tiffany Kessler, Doug and Jenifer Myers, Kevin and Jennifer Oney, Duane Robinson, John and Lisa Wilson, Rita and Jerry Cantu, and Tom and Lori Scheele (collectively, Seneca County Residents).

{¶ 10} Seneca County Residents contend that they have a real and substantial interest in this proceeding and that their interests are not already adequately represented by existing parties in this proceeding. They submit that their intervention will contribute to a just and expeditious resolution of issues raised in this proceeding and that their intervention will neither delay this proceeding nor prejudice parties.

{¶ 11} According to Seneca County Residents, they seek to intervene in this proceeding in order to protect their personal interests that they allege will be detrimentally affected if Republic is permitted to construct its proposed project in close proximity to their homes. Specifically, Seneca County Residents represent that they are long-time residents who own property and live in Seneca County. They contend that their homes will be subjected to excessive noise and shadow flicker caused by Republic's wind turbines. Additionally, they assert that birds, bats, and bald eagles will be harmed and killed as a of the project. Seneca County Residents submit that this market distortion harms all ratepayers including themselves.

{¶ 15} On July 3, 2018, Republic filed its memorandum contra Seneca County Residents' motion to intervene. According to Republic, only those property owners who will experience legitimate impacts from the project have standing to raise concerns in this proceeding. Republic contends that none of the residents should be allowed to raise generalized claims regarding potential impacts without showing that their particular property is affected. Republic submits that living in the same county as the proposed project area is not sufficient to establish a legitimate interest in this proceeding. It therefore opposes the intervention of Jennifer and Doug Myers, Danielle and Chris Zeman, Lisa and John Wilson, Duane Robinson, Carol Burkholder, David Hoover, Jeffrey Hoover, and Rita and Jerry Cantu based on the assertion that the properties are not located within the project area near the proposed turbine locations and, therefore, will not experience any appreciable impacts due to the proposed project.

{¶ 16} In support of its position, Republic states that a number of these residents live a substantial distance away from the any of the proposed turbine locations. In particular, Republic submits that Carol Burkholder lives approximately two miles from any of the proposed turbine locations. The Wilsons and Duane Robinson live over one mile from any proposed turbine. Jennifer and Doug Myers, Danielle and Chris Zeman, and Jeffrey Hoover live over one-half mile from any proposed turbine location. David Hoover lives almost a half mile from any proposed turbine location. Republic posits that because the identified residents do not live in the project area and do not live near any of the proposed turbine sites, they should not be allowed to intervene to raise theoretical concerns that do not actually impact their interests.

{¶ 17} In the event that these residents living outside the project area have any interests in this proceeding, Republic opines that the concerns can be addressed by other parties in this proceeding or through the Board Staff's investigation.

inside the project area. Additionally, this nexus has been established by David P. Hoover, Jeffrey A. Hoover, Doug and Jennifer Myers, and Chris and Danielle Zeman stemming from the fact that their property abuts the project area, which results in them being directly impacted by the proposed project. Therefore, the motions to intervene shall be granted for these individuals.

{¶ 21} Specific to Carol Burkholder, Rita and Jerry Cantu, Duane Robinson, and John and Lisa Wilson, these individuals reside outside of the project area and do not have property that abuts the project area. Therefore, they have failed to demonstrate a sufficiently direct interest at stake in the outcome of this case and the ALJ finds that their motion to intervene should be denied. The ALJ further notes that the interests of these Seneca County Residents may be raised during the local public hearing, currently scheduled for October 2, 2018, for the Board's consideration.

{¶ 22} As noted above, Republic requests that to the extent that intervention is granted to any of the Seneca County Residents, the scope of the permitted intervention should be limited so that arguments regarding alleged increases in the cost of electricity from the operation of the proposed facility are not permitted. The ALJ finds that the question of admissibility of evidence is premature at this point in the proceeding. Therefore, scope of intervention will not be limited at this time. In reaching this determination, the ALJ is not opining on the ultimate admissibility of any specific information. Further, the ALJ recognizes that the Board's authority is to evaluate a proposed facility's effect on environmental values. Determinations regarding the price a customer must pay for electric service and concerns regarding reliability of service are vested with the Commission. *In re Columbus Southern Power Co. and Ohio Power Co., Case No.* 06-309-EL-BTX, Entry (Nov. 20, 2006).

{¶ 28} On June 28, 2018, as amended on August 14, 2018 and August 17, 2018, York Township, Sandusky County, filed a petition to intervene as a party to this proceeding. The township represents it is part of the area in which the proposed facility will be constructed. Additionally, the township states that it has a real and substantial interest in this matter that is not adequately represented by existing parties. Further, the township represents that its involvement will contribute to a just and expeditious resolution of the issues raised and that its intervention will not unduly delay the proceedings.

{¶ 29} No memoranda contra were filed in response to the intervention motions of the OFBF or the townships.

{¶ 30} The ALJ finds that the unopposed motions to intervene filed by the OFBF and the townships demonstrate good cause for permitting intervention and, therefore, should be granted.

{¶ 31} It is, therefore,

{¶ 32} ORDERED, That the motions for intervention be granted in part and denied in part as set forth in this Entry. It is, further,

{¶ 33} ORDERED, That a copy of this Entry be served upon all parties and interested persons of record.

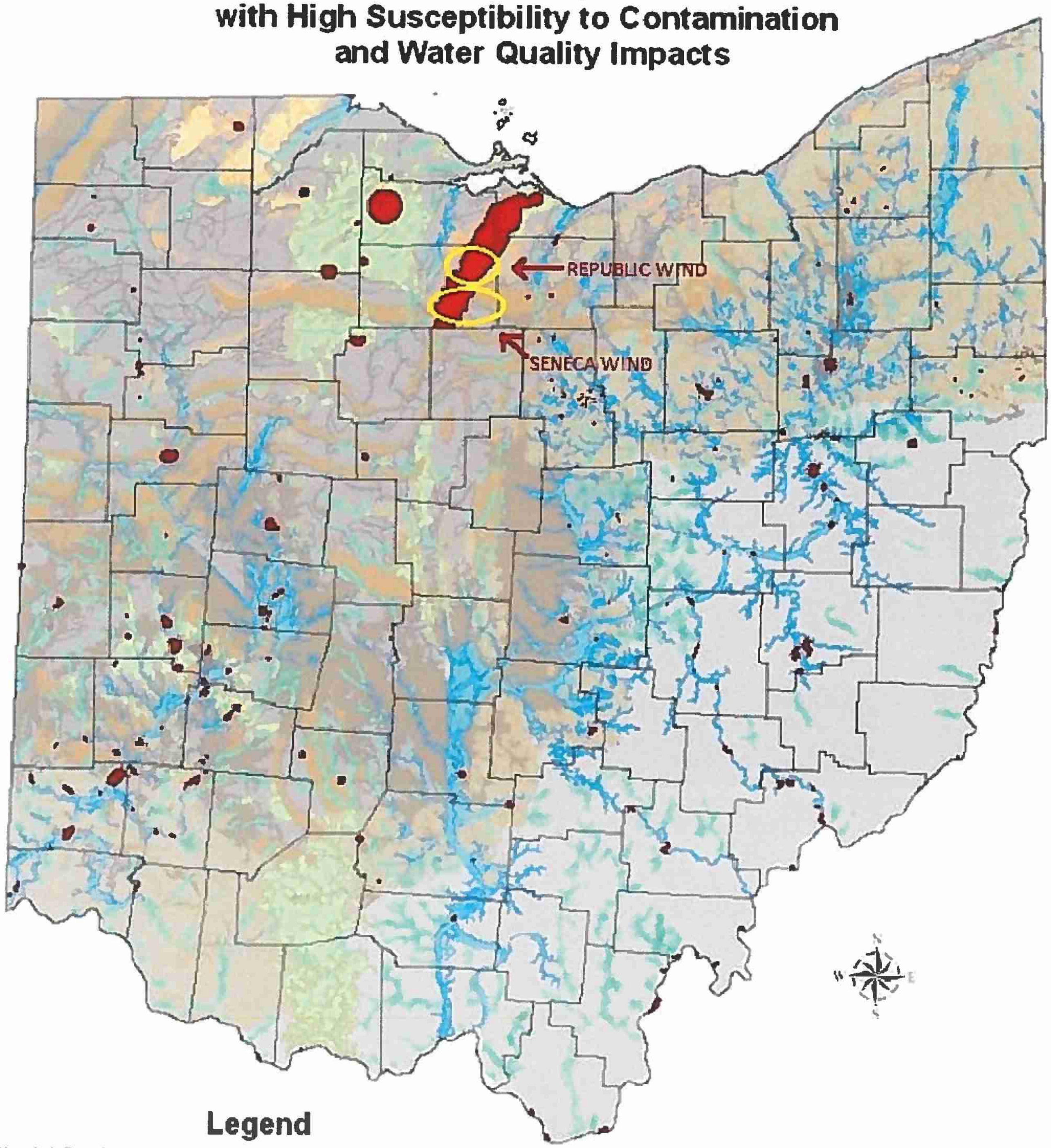
THE OHIO POWER SITING BOARD

/s/ Jay S. Agranoff

By: Jay S. Agranoff
Administrative Law Judge

JRJ/hac/mef

Community PWS using Ground Water with High Susceptibility to Contamination and Water Quality Impacts



Legend

Glacial Geology

- Alluvial
- Beach Ridge
- Buried Valley
- Complex
- End Moraine
- Ground Moraine/Lacustrine
- Outwash/Kame
- Thin Upland
- Unglaciated Region

- Drinking Water Source Protection Areas for Community Public Water Systems using Ground Water with a High Susceptibility to Contamination and Water Quality Impacts
- Potential Karst Region
- County Boundaries

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Joule

Cell Press

Article

Climatic Impacts of Wind Power

Lee M. Miller[1,3,*] and David W. Keith[1,2,*]

SUMMARY

We find that generating today's US electricity demand (0.5 TW_e) with wind power would warm Continental US surface temperatures by 0.24°C. Warming arises, in part, from turbines redistributing heat by mixing the boundary layer. Modeled diurnal and seasonal temperature differences are roughly consistent with recent observations of warming at wind farms, reflecting a coherent mechanistic understanding for how wind turbines alter climate. The warming effect is: small compared with projections of 21st century warming, approximately equivalent to the reduced warming achieved by decarbonizing global electricity generation, and large compared with the reduced warming achieved by decarbonizing US electricity with wind. For the same generation rate, the climatic impacts from solar photovoltaic systems are about ten times smaller than wind systems. Wind's overall environmental impacts are surely less than fossil energy. Yet, as the energy system is decarbonized, decisions between wind and solar should be informed by estimates of their climate impacts.

Context & Scale

Wind power can impact the climate by altering the atmospheric boundary layer, with at least 40 papers and 10 observational studies now linking wind power to climatic impacts. We make the first comparison between the climatic impacts of large-scale wind power and site-scale observations, finding agreement that warming from wind turbines is largest at night. Wind power's climatic impacts will continue to expand as more are installed.

Do these impacts matter? How do these impacts compare to the climate benefits of reducing emissions? We offer policy-relevant comparisons: wind's climatic impacts are about 10 times larger than solar photovoltaic systems per unit energy generated. We explore the temporal trade-off between wind's climatic impacts and the climate benefits it brings by reducing emissions as it displaces fossil fuels. Quantitative comparisons between low-carbon energy sources should inform energy choices in the transition to a carbon-free energy system.

INTRODUCTION

To extract energy, all renewables must alter natural energy fluxes, so climate impacts are unavoidable, but the magnitude and character of climate impact varies widely. Wind turbines generate electricity by extracting kinetic energy, which slows winds and modifies the exchange of heat, moisture, and momentum between the surface and the atmosphere. Observations show that wind turbines alter local climate,[1–10] and models show local- to global-scale climate changes from the large-scale extraction of wind power.[11–15] Previous studies have assessed climate impacts of hydropower,[16] biofuels,[17] and solar photovoltaic systems (PVs).[18] Rapid expansion of renewable energy generation is a cornerstone of efforts to limit climate change by decarbonizing the world's energy system. In addition to climate benefits, wind and solar power also reduce emissions of criteria pollutants (NO_x, SO_x, and $PM_{2.5}$) and toxic pollutants such as mercury that cause significant public health impacts.[19,20] The climate impacts of wind and solar are small compared with the impacts of the fossil fuels they displace, but they are not necessarily negligible. Improved understanding of the environmental trade-offs between renewables would inform choices between low-carbon energy sources. With growth of wind and solar PVs far outstripping other renewables,[21] we combine direct observations of onshore wind power's impacts with a continental-scale model, and compare it to prior estimates of PVs' impacts to assess the relative climate impacts of wind and solar energy per unit energy generation.

Climatic impacts due to wind power extraction were first studied using general circulation models (GCMs). These studies found statistically significant climatic impacts within the wind farm, as well as long-distance teleconnections, with impacts outside the wind farm sometimes as large in magnitude as impacts inside the wind farm.[11–13,22] Note that such impacts are unlike greenhouse gas (GHG)-driven warming, as in some cases wind power's climatic impacts might counteract such GHG

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warming—at least four studies have found that mid-latitude wind power extraction can cool the Arctic.[11,12,23,24] However, these studies often used idealized or unrealistic distributions of turbines installed at unrealistic scales. Model simulations of geometrically simple, isolated wind farms at smaller scales of 3,000–300,000 km^2 (10- to 1,000 times larger than today's wind farms) in windy locations found substantial reductions in wind speed and changes in atmospheric boundary layer (ABL) thickness, as well as differences in temperature,[11,13,14,24] precipitation,[14,25] and vertical atmospheric exchange.[15,26]

We want to assess wind power's climate impacts per unit of energy generation, yet wind's climatic impacts depend on local meteorology and on non-local climate teleconnections. These twin dependencies mean that wind power's impacts are strongly dependent on the amount and location of wind power extraction, frustrating the development of a simple impact metric.

As a step toward an improved policy-relevant understanding, we explore the climatic impacts of generating 0.46 TW_e of wind-derived electricity over the Continental US. This scale fills a gap between the smaller isolated wind farms and global-scale GCM. We model a uniform turbine density within the windiest one-third of the Continental US, and vary the density parametrically.

Our 0.46 TW_e *benchmark scenario* is ~18 times the 2016 US wind power generation rate.[21] We intend it as a plausible scale of wind power generation if wind power plays a major role in decarbonizing the energy system in the latter half of this century. For perspective, the benchmark's electricity generation rate is only 14% of current US primary energy consumption,[25] about the same as US electricity consumption,[27] and about 2.4 times larger than the projected 2050 US wind power generation rate of the *Central Study* in the Department of Energy's (DOE) recent *Wind Vision*.[28] Finally, it is less than one-sixth the technical wind power potential over about the same windy areas of the US as estimated by the DOE.[28,29]

Modeling Framework

We use the WRF v3.3.1 high-resolution regional model[30] with a domain that encompasses the Continental US, forced by boundary conditions from the North American Regional Reanalysis.[31] The *wind farm region* is more than 500 km from the model boundaries, and encompasses only 13% of the domain (shown in Figure 1A). The model configuration used dynamic soil moisture and 31 vertical levels with 3 levels intersecting the turbine's rotor and 8 levels representing the lowermost kilometer. The model is run for a full year after a 1-month spin-up using horizontal resolutions of 10 and 30 km. The wind turbine parametrization was originally released with WRF v3.3,[32] and represents wind turbines as both a momentum sink and turbulent kinetic energy (TKE) source. We updated the wind turbine parameterization to make use of the thrust, power, and TKE coefficients from a Vestas V112 3 MW. This treatment of wind power is very similar to previous modeling studies.[14,15,24]

The advantage of the regional model is that we can use a horizontal and vertical resolution substantially higher than previous global modeling studies,[11–13,22,23,26,33,34] allowing better representation of the interactions of the wind turbines with the ABL. The disadvantage of using prescribed boundary conditions is that our simulations will underestimate the global-scale climatic response to wind power extraction compared with a global model with equivalent resolution, which would allow the global atmosphere to react to the increased surface drag over the US and would reveal climate teleconnections.

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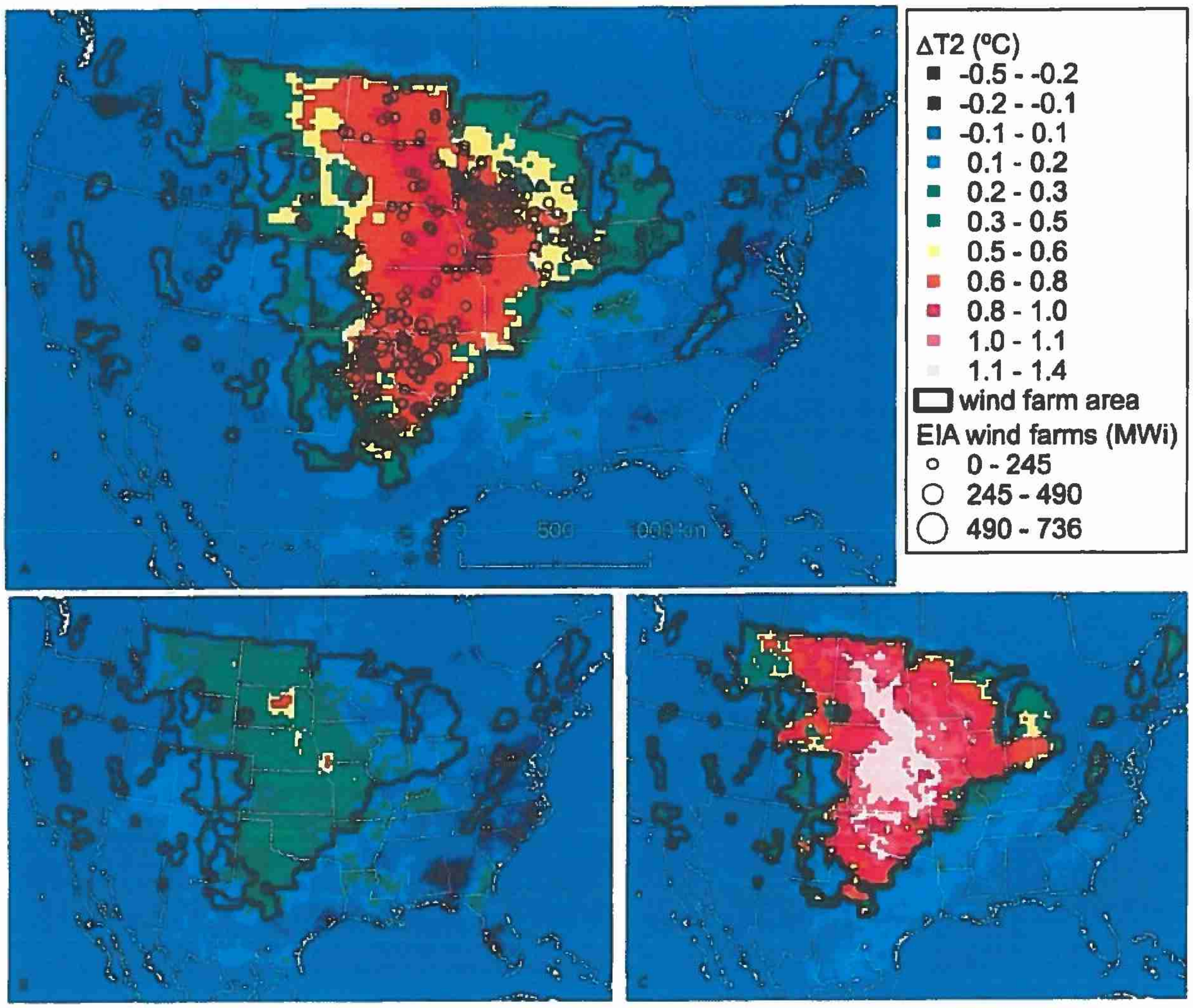

Figure 1. Temperature Response to Benchmark Wind Power Deployment (0.5 MW km^{-2})

(A–C) Maps are 3-year mean of perturbed minus 3-year mean of control for 2-m air temperatures, showing (A) entire period, (B) daytime, and (C) nighttime. The wind farm region is outlined in black, and, for reference, presently operational wind farms are shown as open circles in (A).

We tested horizontal resolution dependence by comparing the 10- and 30-km simulations with a turbine density of 3.0 MW km^{-2} with the respective 2012 controls. Differences in the annual average 2-m air temperature were small, as shown in Figure S1. The following results use a 30-km resolution (about one-ninth of the computational expense) and 2012, 2013, and 2014 simulation periods to reduce the influence of interannual variability. We use four turbine densities (0.5, 1.0, 1.5, and 3.0 MW km^{-2}) within the wind farm region to explore how increased wind power extraction rates alter the climatic impacts.

RESULTS AND DISCUSSION

Figure 1 shows the climate impacts of the benchmark scenario (0.5 MW km^{-2}). The wind farm region experiences warmer average temperatures (Figure 1A), with about twice the warming effect at night compared with during the day (Figures 1B and 1C). Warming was generally stronger nearer to the center of the wind farm region, but perhaps because teleconnections are suppressed by the forced boundary conditions. The climate response is concentrated in the wind farm region, but there are regions well outside the wind farm region also experiencing a climate response. The clearest example here is along the East Coast during the daytime, where average daytime temperatures are 0.1°C–0.5°C cooler (Figure 1B).

To separate the local direct boundary layer impacts from the mesoscale climate changes, we ran a diagnostic simulation with a 250 × 250-km "hole" near the center of the wind farm region, finding that the "hole" experienced about half the warming of the original "no hole" benchmark scenario during 2014 (Table S1 and Figure S2). This suggests that about half the warming effect is attributed to localized changes in atmospheric mixing, with the other half attributed to mesoscale changes, but this requires further study.

Changes in precipitation are small and show no clear spatial correlation (Figure S3). The warming is greatest in an N-S corridor near the center of the wind turbine array, perhaps because of an interaction between wind turbines and the nocturnal low-level jet (LLJ). The LLJ is a fast nocturnal low-altitude wind (>12 m s^{-1} at 0.5 km) common in the US Midwest, which occurs when the atmosphere decouples from surface friction, resulting in a steep vertical temperature gradient[35]—meteorological conditions that might be sensitive to perturbations by wind turbines. We quantified the presence of the LLJ in our control simulation but did not find a strong spatial correlation between the probability of LLJ occurrence and the nighttime warming (Figure S4). To explore mechanisms, we examine the vertical temperature gradient, atmospheric dissipation, and wind speed (Figure S5), and then explore the relationship between warming and these variables using scatterplots (Figure S6). We find some consistency between the dissipation rate of the control and the warming effect of wind turbines, but the correlation is weak.

Figure 2 explores the relationship between changes in vertical temperature gradient, atmospheric dissipation, and the simulated warming. Wind turbines reduce vertical gradients by mixing. During the day, vertical temperature gradients near the surface are small due to solar-driven convection and are only slightly reduced by the turbines. Gradients are larger at night, particularly during summer, and the gradient reduction caused by turbine-induced mixing is larger. The largest warming occurs when the reduction in gradient is strongest and the proportional increase in TKE is largest.

Warming and power generation saturate with increasing turbine density (Figure 3). The temperature saturation is sharper, so the ratio of temperature change per unit energy generation decreases with increasing turbine density. This suggests that wind's climate impacts per unit energy generation may be somewhat larger for lower values of total wind power production.

Power generation appears to approach the wind power generation limit at turbine densities somewhat above the maximum (3.0 MW km^{-2}) we explored. A capacity density of 1.5 MW_i km^{-2} roughly matches that of US wind farms installed in 2016,[36] and that simulation's power density of 0.46 W_e m^{-2} is very close to the 0.50 W_e m^{-2} observed for US wind farms during 2016.[36] The highest turbine density yields an areal (surface) power density of 0.70 W_e m^{-2}, consistent with some previous studies,[15,22,24,26,33] but half the 1.4 W_e m^{-2} assumed possible by 2050 from the same 3.0 MW km^{-2} turbine density into windy regions by the DOE.[28] While we did not compute a maximum wind power generation rate here, extrapolation of

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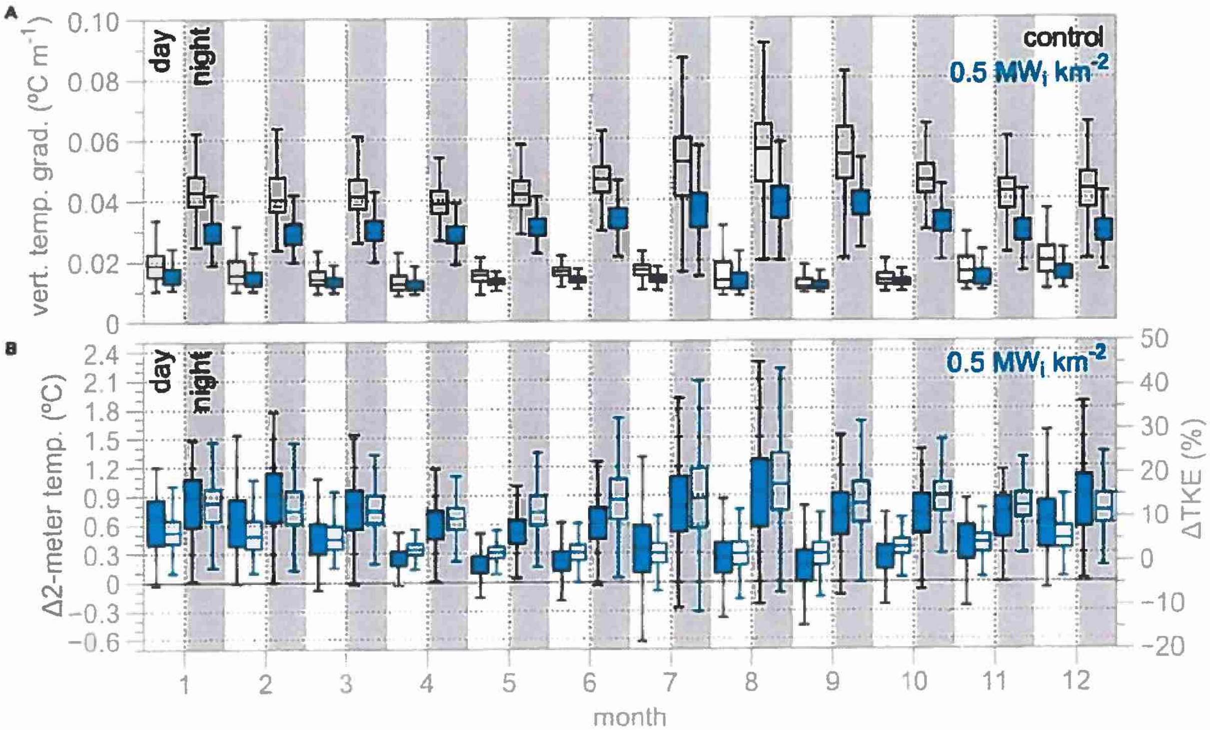

Figure 2. Monthly Day-Night Climate Response to the Benchmark Scenario

(A and B) Average monthly day and night values over the wind farm region for (A) vertical temperature gradient between the lowest two model levels (0–56 and 56–129 m) for the control and benchmark scenario (0.5 MW_i km^{-2}), and (B) differences between the benchmark scenario and control in 2-m air temperature (solid blue boxes) and turbulent kinetic energy (TKE) in the lowest model level (transparent boxes). In both, the vertical line extent shows the standard 1.5•interquartile range, and the box represents the 25th, 50th, and 75th percentiles.

Figure 3 suggests that it is about 2 TW_e, significantly less than the 3.7 TW_e of technical potential estimated by the DOE[28,29] over less land area. Clearly, interactions of wind turbines with climate must be considered in estimates of technical wind power potential.

Interpretation

The climatic impacts of wind power may be unexpected, as wind turbines only redistribute heat within the atmosphere, and the 1.0 W m^{-2} of heating resulting from kinetic energy dissipation in the lower atmosphere is only about 0.6% of the diurnally averaged radiative flux. But wind's climatic impacts are not caused by additional heating from the increased dissipation of kinetic energy. Impacts arise because turbine-atmosphere interactions alter surface-atmosphere fluxes, inducing climatic impacts that may be much larger than the direct impact of the dissipation alone.

As wind turbines extract kinetic energy from the atmospheric flow and slow wind speeds, the vertical gradient in wind speed steepens, and downward entrainment increases.[15] These interactions increase the mixing between air from above and air near the surface. The strength of these interactions depends on the meteorology and, in particular, the diurnal cycle of the ABL.

During the daytime, solar-driven convection mixes the atmosphere to heights of 1–3 km.[35]

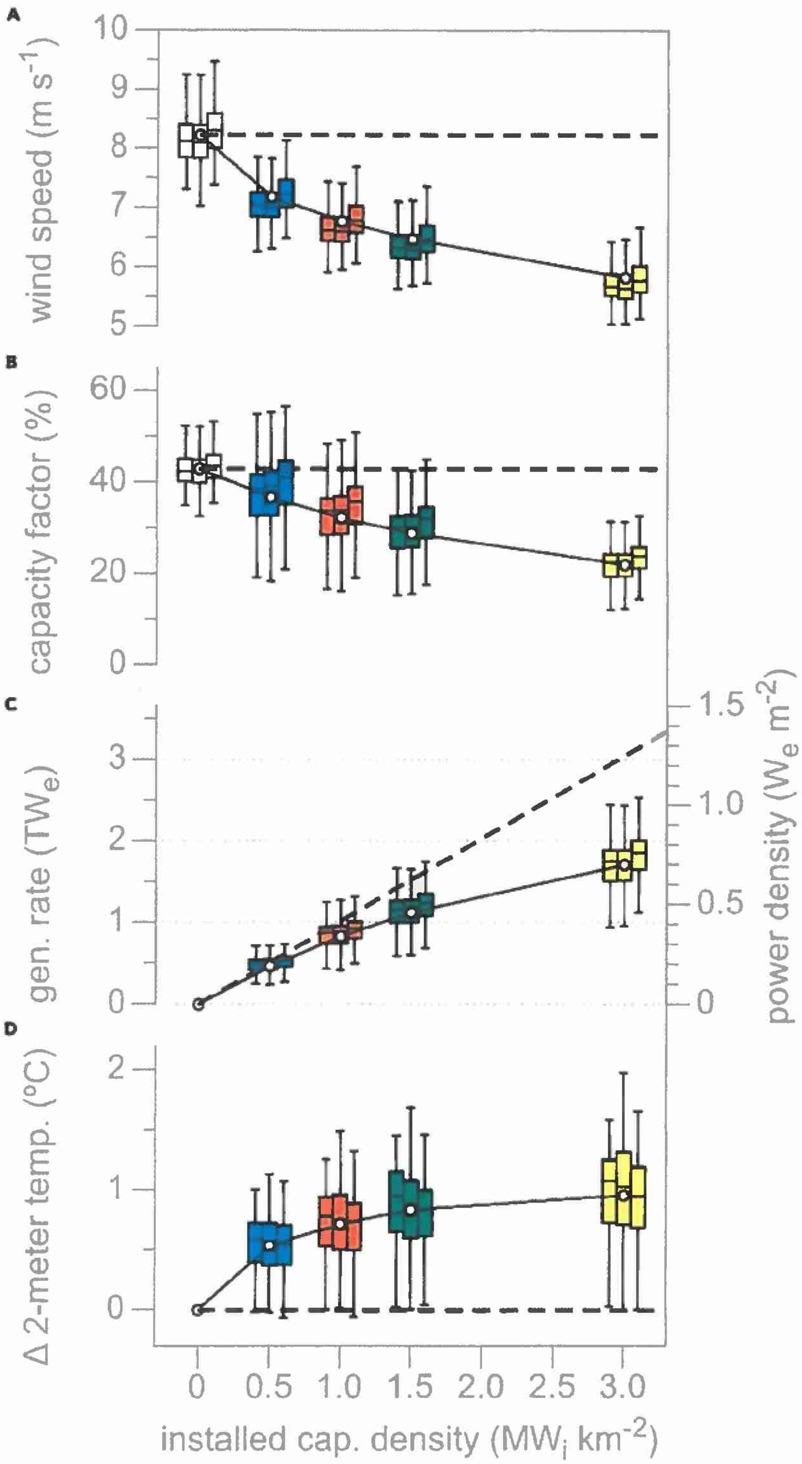

Figure 3. Variation in Mean Response to Changes in Installed Capacity Density

(A–D) The shared x axis is the installed electrical generation capacity per unit area. All values are averages over the wind farm region. (A) Eighty-four-meter hub-height wind speed, (B) capacity

Figure 3. Continued

factor, i.e., the ratio of realized electrical output to generation capacity, (C) power output as a sum and per unit area, and (D) difference in 2-m air temperature. For each value, three distinct years of data (2012–2014 from left to right) are shown as three boxplots (1.5·interquartile range, with 25th, 50th, and 75th percentiles). Colors help group identical installed capacity densities. The 3-year mean is shown using white points and connecting solid lines. Dashed lines illustrate the expected results if climate did not respond to the deployment of wind turbines.

Wind turbines operating during the daytime are enveloped within this already well-mixed air, so climatic impacts such as daytime temperature differences are generally quite small. At night, radiative cooling results in more stable surface conditions, with about 100–300 m of stable air separating the influence of surface friction from the winds aloft.[35] Wind turbines operating at night, with physical extents of 100–150 m and an influence height at night reaching 500 m or more,[15] can entrain warmer (potential temperature) air from above down into the previously stable and cooler (potential temperature) air near the surface, warming surface temperatures. In addition to the direct mixing by the turbine wakes, turbines reduce the wind speed gradient below their rotors and thus sharpen the gradient aloft. This sharp gradient may then generate additional turbulence and vertical mixing.

This explanation is broadly consistent with the strong day-night contrast of our benchmark scenario (Figures 1B and 1C). Within the wind farm region during the day, most locations experience warmer air temperatures, although ~15% of locations show a daytime cooling effect in July-September. At night during July-September, less than 5% of locations show a cooling effect, and the warming effect at night over all months is much larger than during the daytime. This daytime and nighttime warming effect is also larger with higher turbine densities (Figure S7). Finally, the temperature perturbation in the benchmark scenario shows a strong correlation to differences in TKE within the lowest model level from 0 to 56 m (Figure 2B), with these increases in TKE downwind of turbines previously observed in Iowa[4] and offshore Germany,[37] and supporting our explanation that the temperature response is driven by increased vertical mixing (Figure 2).

Observational Evidence of Climatic Impacts

While numerous observational studies have linked wind power to reduced wind speeds and increased turbulence in the turbine wakes,[1,4,7,38,39] ten studies have quantified the climatic impacts resulting from these changes (Table 1).

Three ground-based studies have measured differences in surface temperature[1,5,7] and evaporation.[5] Generally, these ground-based observations show minimal climatic impacts during the day, but increased temperatures and evaporation rates at night.

Seven satellite-based studies have quantified surface (skin) temperature differences. By either comparing time periods before and after turbine deployment, or by comparing areas upwind, inside, and downwind of turbines, the spatial extent and intensity of warming for 28 operational wind farms in California,[40] Illinois,[6] Iowa,[2] and Texas[8–10] has been observed. There is substantial consistency between these satellite observations despite the diversity of local meteorology and wind farm deployment scales. Daytime temperature differences were small and slightly warmer and cooler, while nighttime temperature differences were larger and almost always warmer (Table 1). Interpretation of the satellite data is frustrated by fixed overpass times and clouds that sometimes obscure the surface.

Table 1. Overview of Observational Studies Linking Air Temperature Differences to Wind Farms

Reference	SAT or GND	Period	State	Notes: Climatic Impacts within or Very near to the Operational Wind Farm
Baidya Roy and Traiteur,[1] 2010	GND	53 days	CA	summer; ~1°C increase in 5-m air temperature downwind at night through the early morning; slight cooling effect during the day
Walsh-Thomas et al.[40] 2012	SAT	–	CA	~2°C warmer skin temperatures extending to about 2 km downwind, with visible temperature differences to 12 km downwind
Zhou et al.[9] 2012	SAT	9 years	TX	JJA night = +0.72°C, DJF night = +0.46°C; JJA day = −0.04°C; DJF day = +0.23°C; warming is spatially consistent with the arrangement of wind turbines
Zhou et al.[10] 2013	SAT	6 years	TX	QA1 values: DJF night = +0.22°C, MAM night = +0.29°C, JJA night = +0.35°C, SON night = 0.40°C, DJF day = +0.11°C, MAM day = −0.11°C, JJA day = +0.17°C, SON day = −0.04°C
Zhou et al.[10] 2013	SAT	2 years	TX	QA1 values: DJF night = −0.01°C, MAM night = +0.42°C, JJA night = +0.67°C, SON night = 0.47°C, DJF day = +0.14°C, MAM day = −0.42°C, JJA day = +1.52°C, SON day = +0.12°C
Xia et al.[8] 2016	SAT	7 years	TX	DJF night = +0.26°C, MAM night = +0.40°C, JJA night = +0.42°C, SON night = +0.27°C, Annual night = +0.31°C, DJF day = +0.18°C, MAM day = −0.25°C, JJA day = −0.26°C, SON day = −0.02°C, Annual day = −0.09°C
Harris et al.[2] 2014	SAT	11 years	IA	MAM night = +0.07°C, JJA night = +0.17°C, SON night = +0.15°C
Rajewski et al.[4] 2013	GND	122 days	IA	along the edge of a large wind farm directly downwind of ~13 turbines; generally cooler temperatures (0.07°C) with daytime periods that were 0.75°C cooler and nighttime periods that were 1.0–1.5°C warmer
Rajewski et al.[5] 2014	GND	122 days	IA	along the edge of a large wind farm downwind of ~13 turbines co-located with corn and soybeans; night-sensible heat flux and CO_2 respiration increase 1.5–2 times and wind speeds decrease by 25%–50%; daytime H_2O and CO_2 fluxes increase 5-fold 3–5 diameters downwind
Slawsky et al.[6] 2015	SAT	11 years	IL	DJF night = +0.39°C, MAM night = +0.27°C, JJA night = +0.18°C, SON = +0.26°C; Annual = +0.26°C
Smith et al.[7] 2013	GND	47 days	confidential	Spring; nighttime warming of 1.9°C downwind of a ~300 turbine wind farm

SAT, satellite-based observations; GND, ground-based observations. Note that measurements identified as the same state were completed over the same wind farms.

Although our benchmark scenario is very different in scale and turbine placement compared with operational wind power, it is nevertheless instructive to compare our simulation with observations. We compare results at a single Texas location (100.2°W, 32.3°N) where one of the world's largest clusters of operational wind turbines (~200 km^2, consisting of open space and patchy turbine densities of 3.8–4.7 MW km^{-2})[41] has been linked to differences in surface temperature in 3 of the observational studies in Table 1. Weighting the observations by the number of observed-years, the Texas location is 0.01°C warmer during the day and 0.29°C warmer at night (data in Table S2). Our benchmark scenario with a uniform turbine density of 0.5 MW km^{-2} at this location is 0.33°C warmer during the day and 0.66°C warmer at night. To explore the quantitative correlation between the seasonal and diurnal response, we take the 8 seasonal day and night values as independent pairs (Table S2), and find that the observations and the simulations are strongly correlated (Figure 4). This agreement provides strong evidence that the physical mechanisms being modified by the deployment of wind turbines are being captured by our model. This mechanism could be tested more directly if temperature observations upwind and downwind of a large turbine array were available at a high temporal resolution (<3 hr).

Limitations of Model Framework

Climate response is partly related to the choice and placement of wind turbine(s). We modeled a specific 3.0-MW turbine, but future deployment may shift to wind turbines with taller hub heights and larger rotor diameters. We also assumed

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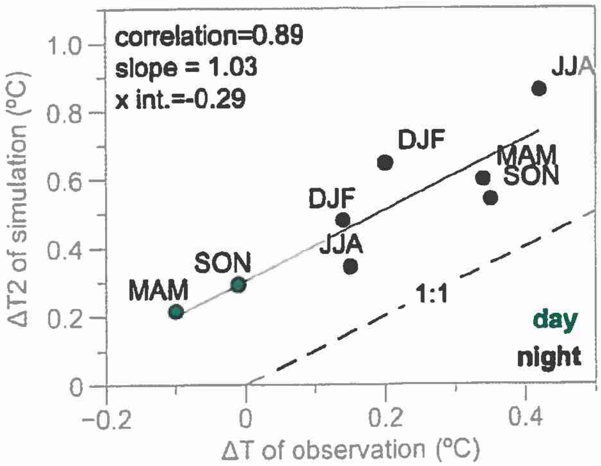

Figure 4. Comparison of Observations and Simulations for the Texas Location (Table 1)
We compare day and night response over four seasons. Observations are surface (skin) temperature differences. Simulation is differences in 2-m air temperatures between the benchmark scenario (0.5 MW km^{-2}) and control. Note that while correlation over eight points is high, the simulated response is larger, likely due to the much larger perturbed area and the difference between skin and 2 m air temperature.

that turbines were evenly spaced over the wind farm region, but real turbine deployment is patchier, potentially also altering turbine-atmosphere-surface interactions.

The model's boundary conditions are prescribed and do not respond to changes caused by wind turbines. Yet prior work has established that non-local climate responses to wind power may be significant,[12] suggesting that simulating our benchmark scenario with a global model (no boundary conditions restoring results to climatology) would allow possible climatic impacts outside the US to be assessed. Removal of the boundary conditions might also increase the warming in the wind farm region. The 3-year simulation period was also completed in 1-year blocks, so we do not simulate the response of longer-term climate dynamics influenced by variables such as soil moisture. Finally, model resolution influenced the estimated climatic impacts. Simulations with a 10-km horizontal resolution and the highest turbine density of 3.0 MW km^{-2} caused 18% less warming than the 30-km simulation (+0.80°C and +0.98°C). Simulations using a global model with an unequally spaced grid with high-resolution over the US could resolve some of these uncertainties.

Comparing Climatic Impacts to Climatic Benefits

Environmental impacts of energy technologies are often compared per unit energy production.[42] Because a central benefit of low-carbon energies like wind and solar is reduced climate change, dimensionless climate-to-climatic comparisons between the climate impacts and climate benefits of reduced emissions are relevant for public policy.

Climate impacts will, of course, depend on a range of climate variables that would need to be examined in a comprehensive impact assessment. In this analysis we nevertheless use 2-m air temperature as a single metric of climate change given (1) that there are important direct impacts of temperature, (2) that temperature change is strongly correlated with other important climate variables, and (3) that use of temperature as a proxy for other impacts is commonplace in climate impacts assessments. Limitations and caveats of our analysis are addressed in the following sub-section.

When wind (or solar) power replace fossil energy, they cut CO_2 emissions, reducing GHG-driven global climate change, while at the same time causing climatic impacts as described above and elsewhere.[1–15,22–26,34,40,43–45] The climatic impacts differ in (at least) two important dimensions. First, the direct climatic impact of wind power is immediate but would disappear if the turbines were removed, while the climatic benefits of reducing emissions grows with the cumulative reduction in emissions and persists for millennia. Second, the direct climatic impacts of wind power are predominantly local to the wind farm region, while the benefits of reduced emissions are global. We revisit and elaborate these differences in a systematic list of caveats at the end of this subsection.

As a step toward a climate-impact to climate-benefit comparison for wind, we compare warming over the US. We begin by assuming that US wind power generation increases linearly from the current level to 0.46 TW_e in 2080 and is constant thereafter. We estimate the associated warming by scaling our benchmark scenario's temperature differences linearly with wind power generation. The amount of avoided emissions—and thus the climate benefit—depends on the emissions intensity of the electricity that wind displaces. We bracket uncertainties in the time evolution of the carbon-intensity of US electric power generation in the absence of wind power by using two pathways. One pathway assumes a static emissions intensity at the 2016 value (0.44 $kgCO_2\ kWh^{-1}$), while the second pathway's emissions intensity decreases linearly to zero at 2100, which is roughly consistent with the GCAM model[46] that meets the IPCC RCP4.5 scenario. The two emissions pathways are then reduced by the (zero emission) wind power generation rate at that time (Figure 5C). The first pathway likely exaggerates wind power's emission reductions, while the second reflects reduced climate-benefit for wind in a transition to a zero-carbon grid that might be powered by solar or nuclear.

It is implausible that the US would make deep emissions cuts while the rest of the world continues with business-as-usual, so we include a third pathway, which functions just like the first pathway, except that the global (rather than just US) electricity emissions intensity declines to zero (Figure S8)

We estimate wind's reduction in global warming by applying the two US and one global emission pathways to an emissions-to-climate impulse response function.[47] We convert these global results to a US warming estimate using the 1.34:1 ratio of US-to-global warming from IPCC RCP4.5 and RCP8.5 ensemble means (Figure S9,[48]).

The benchmark scenario's warming of 0.24°C over the Continental US and 0.54°C over the wind farm region are small-to-large depending on the baseline. Climatic impacts are small if compared with US temperature projections— historical and ongoing global emissions are projected to cause the Continental US to be 0.24°C warmer than today by the year 2030 (Figure S8). Assuming emissions cuts are implemented globally, then the climatic impacts of wind power affecting the US in 2100 are approximately equivalent to the avoided warming from reduced global emissions (green region of Figure 5D). Climatic impacts are large if the US is the only country reducing emissions over this century (blue and gray shaded regions of

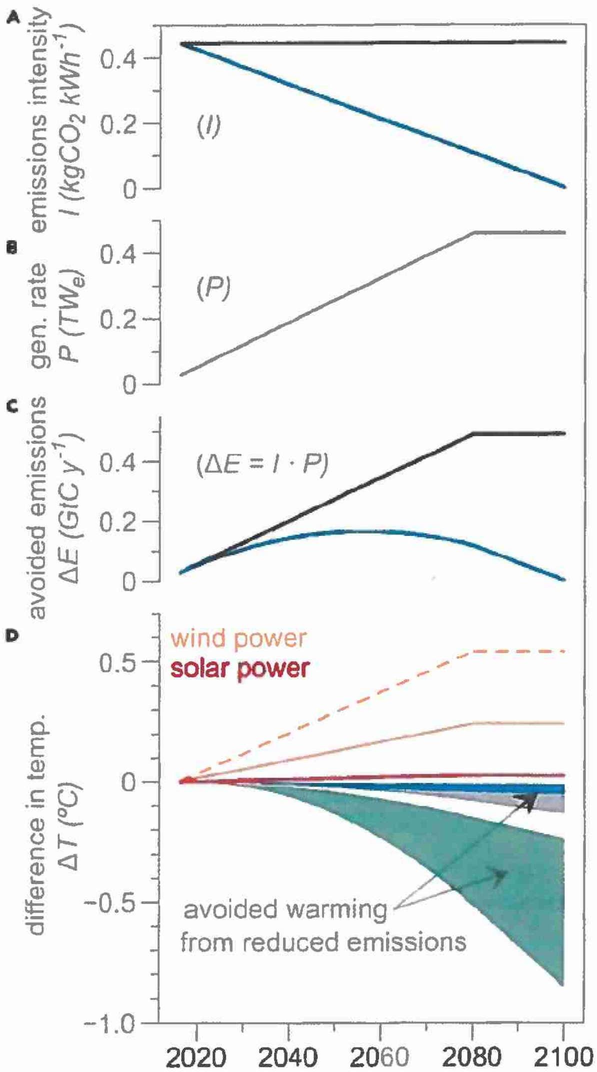

Figure 5. Climate Warming Impacts Compared to Climate Benefits of Reduced Emissions

(A) Two US scenarios, static (black) and declining (blue) emissions intensity, *I*, from US electric power.

(B) A scenario in which power output, *P*, from wind or solar power increases to our benchmark scenario's 0.46 TWe by 2080.

(C and D) Avoided emissions computed as $\Delta E = I \times P$ (C) and the resulting 2-m temperature differences within the wind farm region (dotted lines) and the Continental US (solid lines) (D). Values for wind power linearly scaled from our benchmark scenario, while values for solar power are derived from Nemet.[18] For comparison, the avoided warming of the Continental US from reduced emissions is shown for the static US scenario (gray) and the declining US scenario (blue). The green area shows the avoided warming of the Continental US if global electricity emissions were zero by 2080. The range of avoided warming for each pathway is estimated from the min and max values within the emissions-to-climate impulse response function.

Figure 5D). Timescale matters because climatic impacts are immediate, while climate benefits grow slowly with accumulated emission reductions. The longer the time horizon, the less important wind power's impacts are compared with its benefits (Box 1).

Box 1. Limitations of Using these Results to Compare the Climatic Impacts of Wind Power to Climate Change from Long-Lived Greenhouse Gases

The comparison above suggests that if US electricity demand was met with US-based wind power, the wind farm array would need to operate for more than a century before the warming effect over the Continental US caused by turbine-atmosphere interactions would be smaller than the reduced warming effect from lowering emissions. This conclusion is subject to a number of caveats including:

- Fundamentally different mechanisms cause warmer temperatures from climate change compared with wind power. Increased GHG concentrations reduce radiative heat losses to space, trapping more heat in the atmosphere and causing warmer surface temperatures. Wind power does not add more heat to the atmosphere—wind turbines redistribute heat by mixing and alter large-scale flows both which can change climate.
- Our comparison was based solely on surface air temperature differences. Wind turbines and GHGs both alter a host of interrelated climate variables. The use of surface temperature as the sole proxy for climate impacts may bias the resulting ratio of impacts-to-benefits in either direction.
- Climate impacts of the benchmark scenario will likely be larger and more widespread if we did not use forced boundary conditions, which prevents any feedbacks from the large-scale circulation.
- Results depend on the wind electricity generation rate, consistent with previous work.[11] Our results (Figure 3) suggest the temperature response is *roughly* linear to the generation rate and power density. To the extent that we see deviations from linearity (Figure S7), climate impacts per unit generation are larger for lower turbine densities.
- Results depend on the spatial distribution and density of wind turbines. We assumed that the windiest areas would be exploited and that developers would use low turbine densities to maximize per-turbine generation. Based on simulated results with higher turbine densities (Figure 3), doubling the turbine density over an area half as large as the benchmark scenario might generate almost the same power as the benchmark scenario, while increasing warming over this smaller region by only about a third.
- Our comparison metric ignores many possible benefits and drawbacks of the climate impacts caused by wind power deployment, including:
  - Arctic cooling shown in most large-scale wind power modeling studies.[11,23,24,45]
  - Warmer minimum daily temperatures reduce the incidence and severity of frost, and lengthen the growing season. Compared to the control, the growing season of the wind farm region was 8 days longer in our benchmark scenario, and 13 days longer with 3.0 MW_i km^{-2}.
  - Some locations experience cooler average temperatures during the summer (Figure 2B), consistent with observations,[1,4] and could reduce heat stress.
  - Warmer minimum daily temperatures have been observed to reduce crop yield.[49]
  - Warmer minimum temperatures could influence insect life history in unknown ways.[50]
- The comparison depends on area-weighting. We used equal weighting but one could consider weighting by, for example, population or agricultural production.
- The comparison depends very strongly on the time horizon. We examined the century timescale consistent with Global Warming Potentials, but there is no single right answer for time discounting.[51,52]
- Finally, results depend on the comparison of US and global-scale impacts and benefits: our model framework prevents global-scale analyses, but, assuming a substantial fraction of the warming effect occurred where US wind turbines were operating, global area-weighted benefits would offset the climatic impacts sooner than if impacts and benefits were quantified over just the US (as done here).

Implications for Energy System Decarbonization

Wind beats fossil fuels under any reasonable measure of long-term environmental impacts per unit of energy generated. Assessing the environmental impacts of wind power is relevant because, like all energy sources, wind power causes climatic impacts. As society decarbonizes energy systems to limit climate change, policy makers will confront trade-offs between various low-carbon energy technologies such as wind, solar, biofuels, nuclear, and fossil fuels with carbon capture. Each technology benefits the global climate by reducing carbon emissions, but each also causes local environmental impacts.

Our analysis allows a simple comparison of wind power's climate benefits and impacts at the continental scale. As wind and solar are rapidly growing sources of low-carbon electricity, we compare the climate benefit-to-impact ratio of wind and solar power.

The climate impacts of solar PVs arise from changes in solar absorption (albedo). A prior study estimated that radiative forcing per unit generation increased at 0.9 mWm^{-2}/TW_e, in a scenario in which module efficiency reaches 28% in 2100 with installations over 20% rooftops, 40% grasslands, and 40% deserts.[18] Assuming that the climatic impact is localized to the deployment area and using a climate

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sensitivity of 0.8K/Wm^{-2},[53] generating 0.46 TW_e of solar PVs would warm the Continental US by 0.024°C. This warming effect is 10-times smaller than wind's (0.24°C, Figure 5D) for the same energy generation rate. This contrast is linked to differences in power density and thus to the areal footprint per unit energy—US solar farms presently generate about 5.4 $W_e\,m^{-2}$, while US wind farms generate about 0.5 $W_e\,m^{-2}$.[36] We speculate that solar PVs' climatic impacts might be reduced by choosing low albedo sites to reduce impacts or by altering the spectral reflectivity of panels. Reducing wind's climatic impacts may be more difficult, but might be altered by increasing the height of the turbine rotor above the surface distance to reduce interactions between the turbulent wake and the ground, or switching the turbines on or off depending on meteorological conditions.

In agreement with observations and prior model-based analyses, US wind power will likely cause non-negligible climate impacts. While these impacts differ from the climate impacts of GHGs in many important respects, they should not be neglected. Wind's climate impacts are large compared with solar PVs. Similar studies are needed for offshore wind power, for other countries, and for other renewable technologies. There is no simple answer regarding the *best* renewable technology, but choices between renewable energy sources should be informed by systematic analysis of their generation potential and their environmental impacts.

SUPPLEMENTAL INFORMATION

Supplemental Information includes nine figures and two tables and can be found with this article online at https://doi.org/10.1016/j.joule.2018.09.009.

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AUTHOR CONTRIBUTIONS

Conceptualization, L.M.M. and D.W.K.; Methodology, L.M.M.; Investigation, L.M.M. and D.W.K.; Writing – Original Draft, L.M.M. and D.W.K.; Writing – Review & Editing, L.M.M. and D.W.K.; Visualization, L.M.M. and D.W.K.; Funding Acquisition, D.W.K.

DECLARATION OF INTERESTS

D.W.K. is an employee, shareholder, and executive board member at Carbon Engineering (Squamish, BC). Carbon Engineering is developing renewable electricity to fuels projects and is developing procurement contracts for wind and solar power.

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JOUL, Volume 2

Supplemental Information

Climatic Impacts of Wind Power

Lee M. Miller and David W. Keith

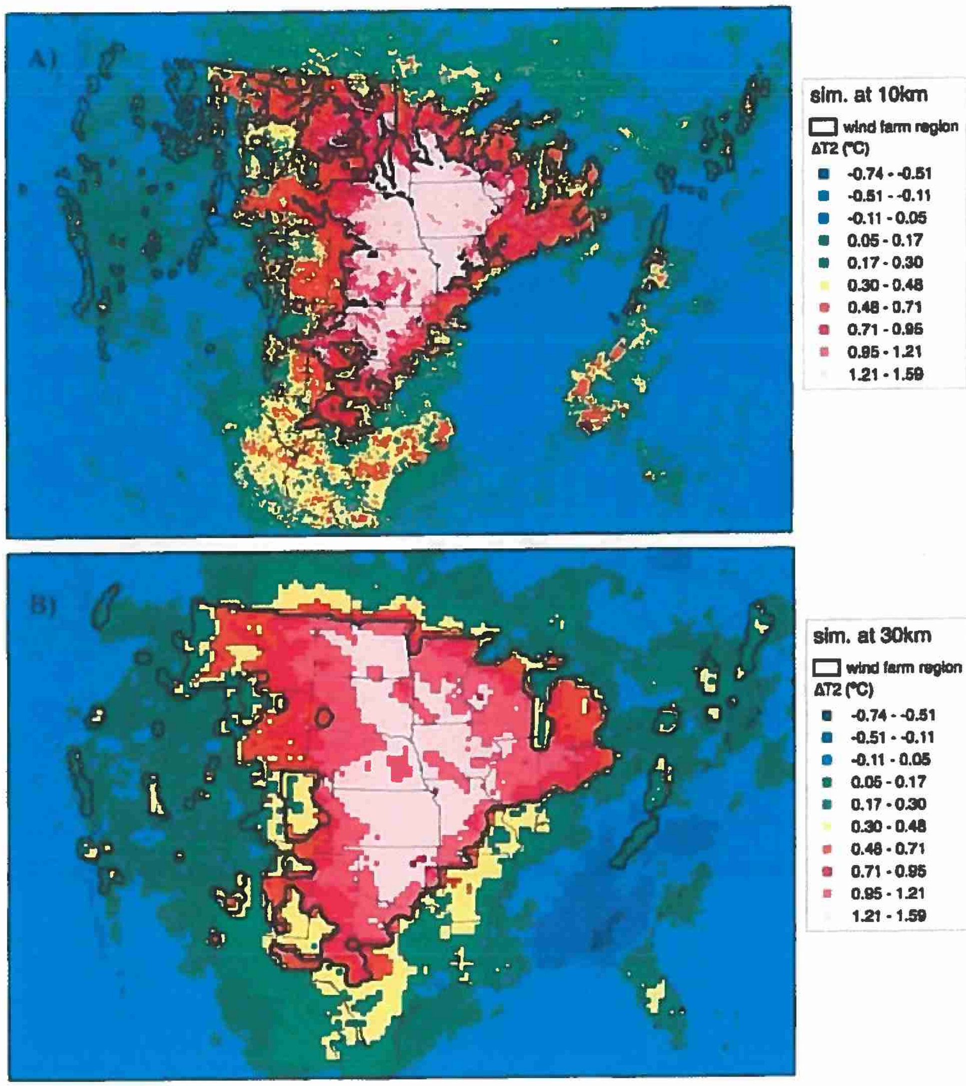

Fig. S1.

Annual mean 2-meter air temperature differences over 2012 resulting from the deployment of a turbine density of 3 MW km^{-2} into the *wind farm regions* (black outlined areas), simulated using **A)** 10 km horizontal resolution, and **B)** 30 km horizontal resolution. The wind farm regions are spatially different. Based on control conditions, the wind farm region in the 10 km simulation encompasses 27% of the Continental US (*i.e.* 2012 mean 80 meter wind speed greater than 7.6 m s^{-1}). The wind farm region of the 30 km simulation encompasses 31% of the Continental US land area, and is identified as the 2012-2014 mean 80-meter wind speed greater than 7.5 m s^{-1}.

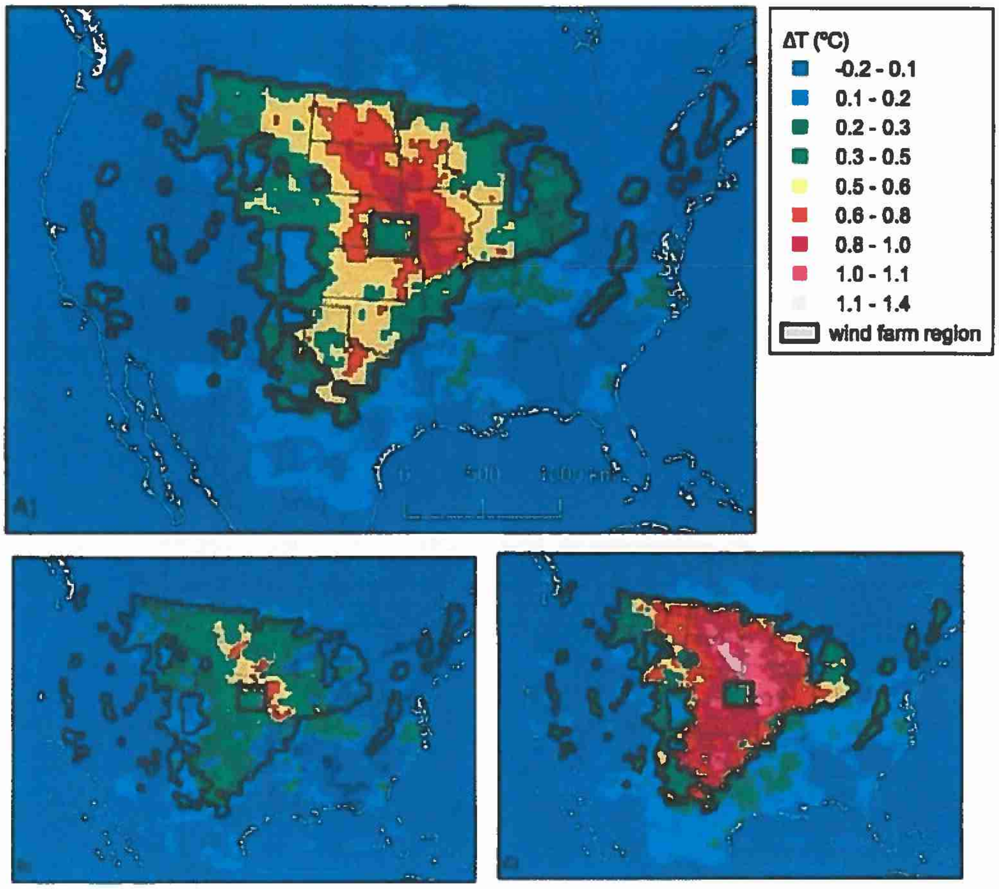

Fig. S2.

2-meter air temperature response to benchmark wind power deployment (0.5 MW_i km^{-2}), but with a 250x250km absence of wind turbines in southeast Nebraska and comparing the year 2014. This is in contrast to Figure 1 of the main text, where the Nebraska hole is not included and a 3-year (2012-2014) is shown. Maps are annual means over 2014 of perturbed minus control for 2-meter air temperatures, showing (A) entire period, (B) daytime, and (C) nighttime. The wind farm region is outlined in black. Mean values within the hole are noted in Table S1.

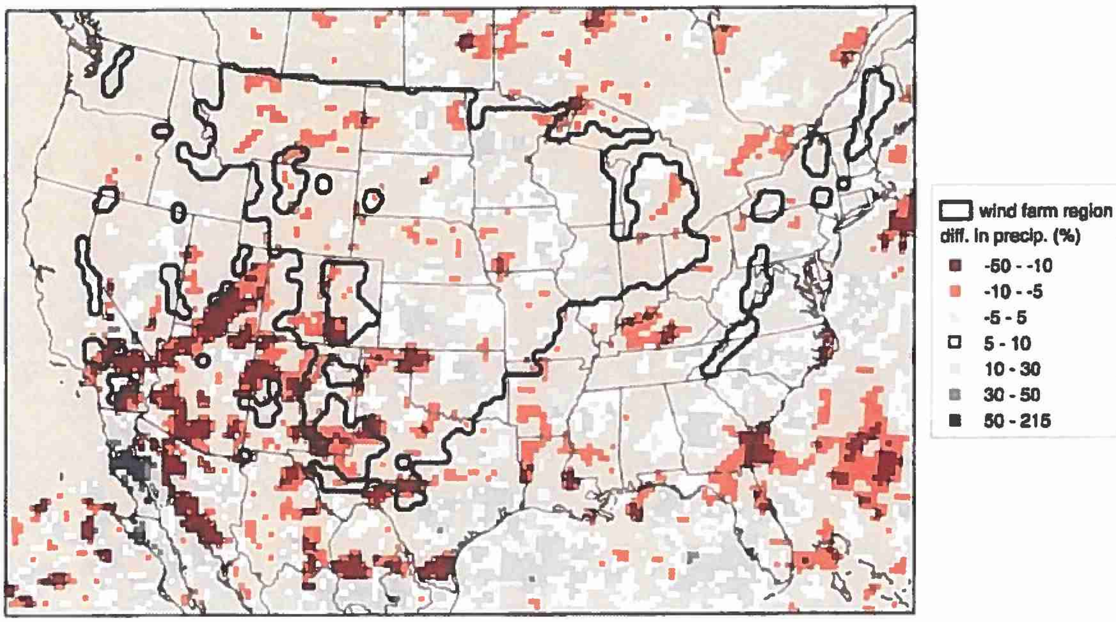

Fig. S3

Mean (2012-2014) precipitation differences between the *benchmark scenario* (0.5 MW km^{-2}) and the control. The black outlined area delineates the wind farm region. Overall, precipitation increased by 2% within the wind farm region.

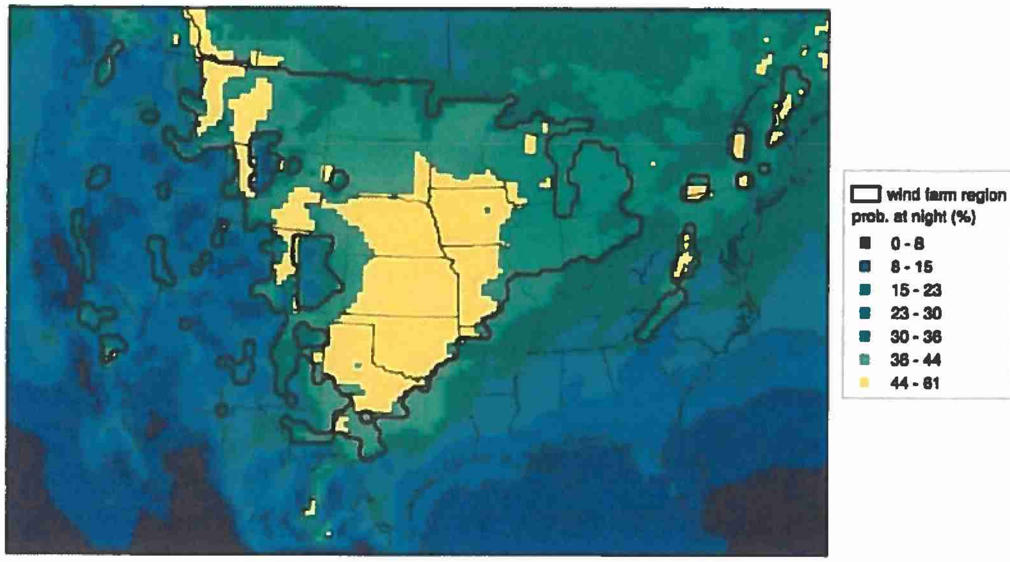

Fig. S4

Probability of the LLJ at night over the 3-year (2012-2014) period based on control conditions, defined as wind speeds greater than 12 m s^{-1} within 500m of the ground surface. The wind farm region is outlined in black.

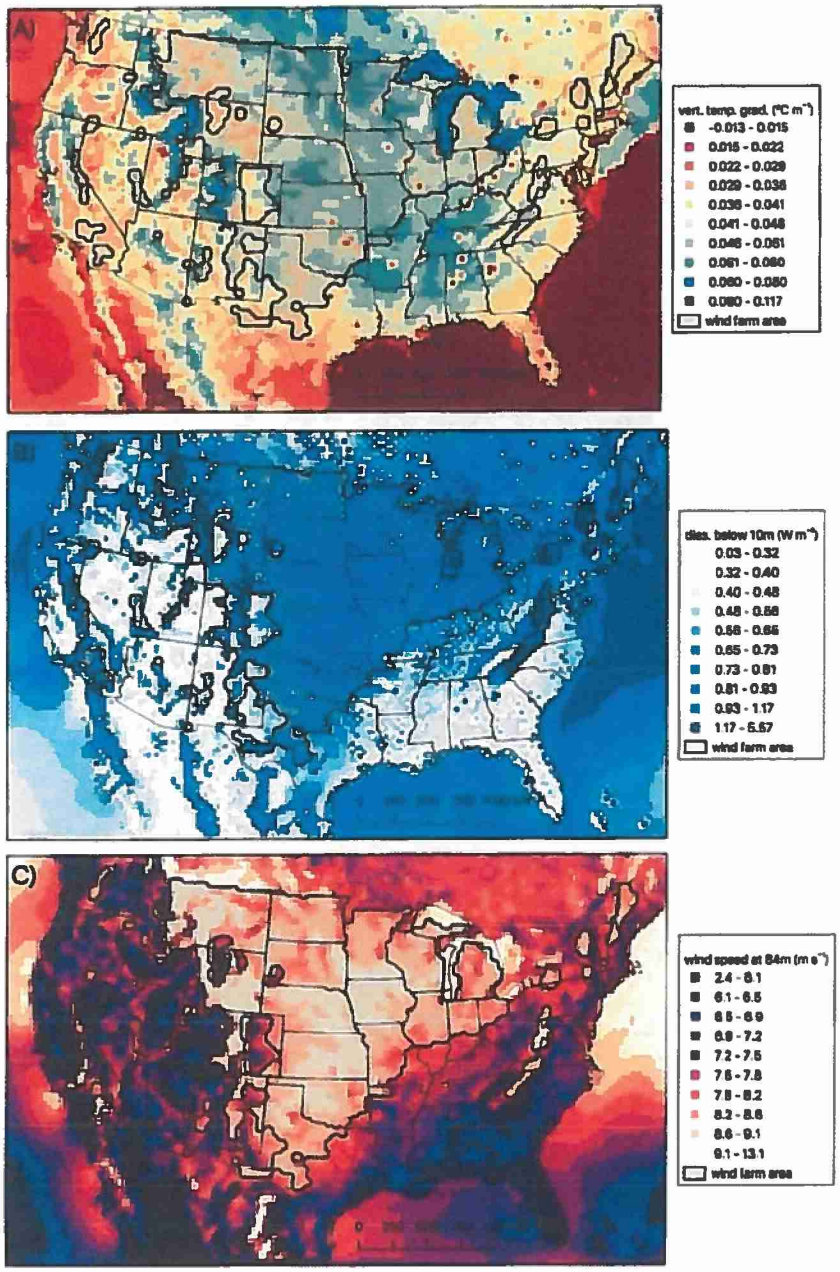

Fig. S5
3-year mean conditions at night of the control simulation to help understand the spatial pattern of nighttime warming (main text Fig. 1C), **A)** vertical gradient in virtual potential temperature between the lowest two model levels (0-56m, 56-129m), **B)** surface dissipation within 10m of the surface, derived as $\rho u_*^{2} \cdot (v_{10})$, where ρ is the air density, u_* is the friction velocity, and v_{10} is the 10-meter wind speed, **C)** 84-meter wind speed (hub-height of the wind turbines). Note, the spottiness in B&C corresponds to cities in the US Midwest and Southeast.

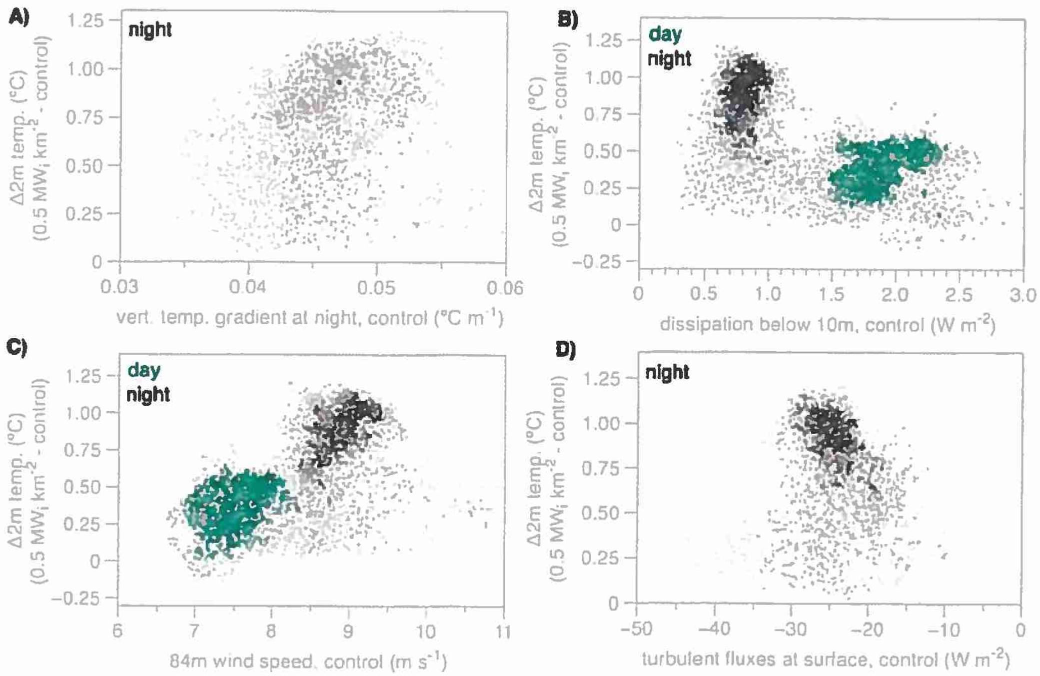

Fig. S6

Comparing 3-year means of control variables to differences in 2-meter air temperature between the benchmark scenario (0.5 MW_i km^{-2}) and the control for each grid point within the wind farm region. **A)** vertical temperature gradient between the lowest 2 model levels (0-56m, 56-129m), **B)** dissipation within 10m of the surface, derived as $\rho u_*^2 \cdot (v_{10})$, where ρ is the air density, u_* is the friction velocity, and v_{10} is the 10-meter wind speed, **C)** 84-meter (hub-height) wind speed, and **D)** turbulent fluxes (sensible heat flux + latent heat flux). 'Night' values in A,B,C correspond to the maps in Fig. S5.

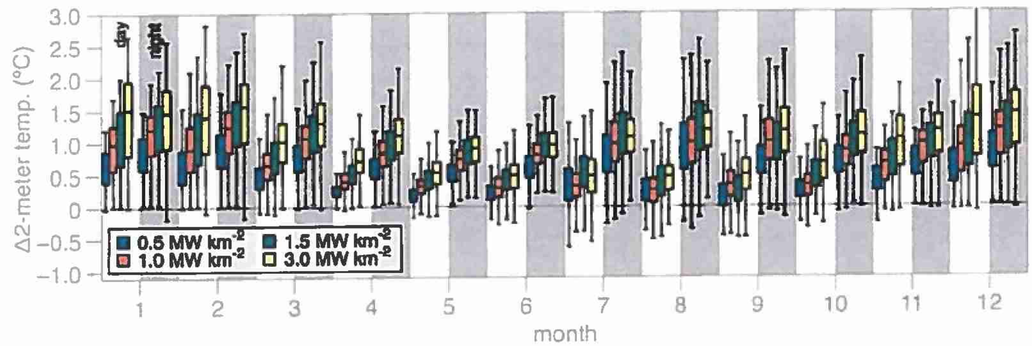

Fig. S7
Day and night 3-year monthly mean 2-meter air temperature differences over the wind farm region between the various turbine densities and the control simulation. The blue box-whisker plot data is the same at in Fig. 1D. The vertical line extent encompasses 1.5-times the interquartile range and the box represents the 25th, 50th, and 75th percentiles.

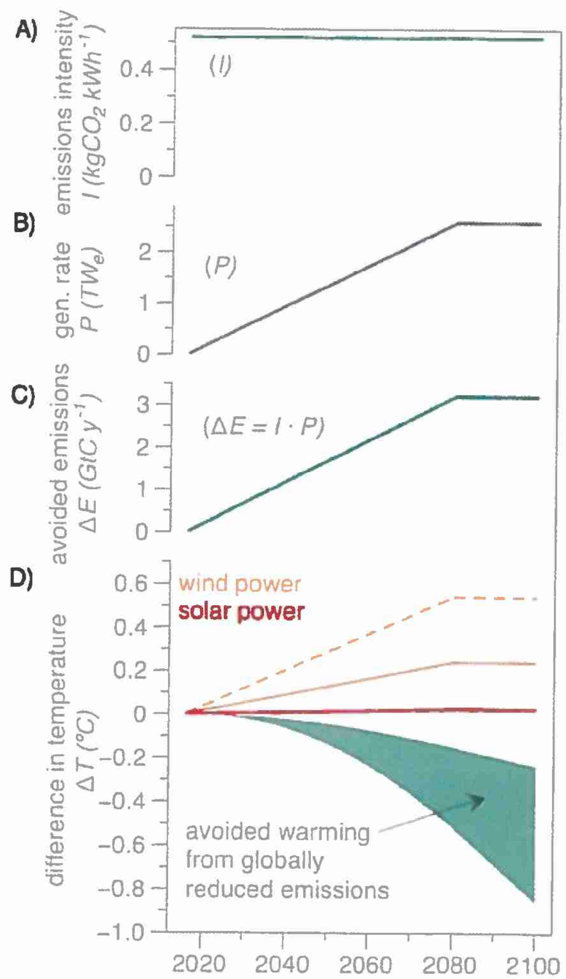

Fig. S8
Companion plot to Fig. 4 of the main text. Climate warming impacts compared to climate benefits of reduced emissions. **(A)** Static global emissions intensity, reflecting the present-day. **(B)** A scenario in which power output, *P*, from a zero-emissions renewable increases to 2.6 TW_e by 2080 and is constant thereafter. **(C)** Avoided emissions computed as $\Delta E = I \times P$, and **(D)** the resulting 2-meter temperature differences within the wind farm region (dotted lines) and the Continental US (solid lines). Values for wind power linearly scaled from the 0.46 TW_e *benchmark scenario* of the main text, while values for solar are derived from[18]. The green area shows the avoided Continental US warming if all global electricity emissions were zero in 2080, with the range estimated from the min- and max-values within the emissions-to-climate impulse response function.

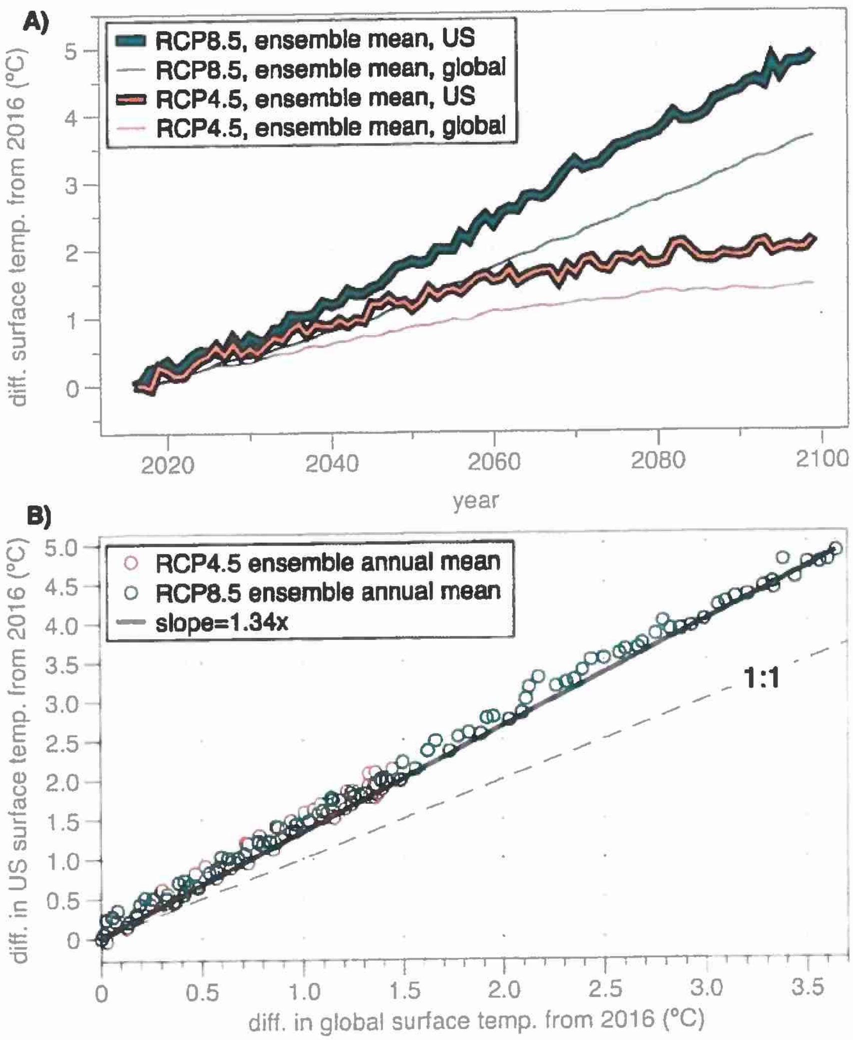

Fig. S9

To estimate the US warming from the global warming estimates from the emissions-to-climate impulse response function, we use the RCP4.5 and RCP8.5 ensemble mean data of Karmalkar et al. (2017); **A)** surface temperature data from 2016 over the Continental US and globally, **B)** using 2016 as the baseline temperature, comparing the difference in global surface temperatures and US surface temperatures. We used the statistical relationship in (B) to rescale the estimates of avoided global warming to estimates of avoided US warming in Fig. 5D.

Table S1. 2-meter air temperature response within the 'hole' region during 2014. Values identified as '0.5 MW_i km^{-2}; no hole' correspond to the original model setup and accompanying Fig. 1, while the '0.5 MW_i km^{-2}; hole' correspond to the results shown in the above Figure. Values within parentheses note the temperature difference from the control.

	control	0.5 MW_i km^{-2}; no hole	0.5 MW_i km^{-2}; hole
all	11.63°C	12.44°C (+0.81°C)	12.02°C (+0.39°C)
day	16.86 °C	17.40°C (+0.54°C)	17.25°C (+0.39°C)
night	6.39 °C	7.48°C (+1.09°C)	6.78°C (+0.39°C)

Table S2.

Values used for the comparison in Fig. 3. Specifics of the reference and the analysis period are noted on the left, as well as the simulation data from our benchmark scenario at the Texas location (100.2°W, 32.3°N). Average day and night values were calculated for the observations to allow for a comparison to the simulation data (day = solar shortwave down > 1 W m^{-2}; night = solar shortwave down < 1 W m^{-2}).

		December - February						March - May					
		DAY			NIGHT			DAY			NIGHT		
Reference	Analysis Period	avg.	10:30	13:30	avg.	22:30	1:30	avg.	10:30	13:30	avg.	22:30	1:30
Zhou et al., 2013, Table 7 QA1 values, ΔT, °C	(2009,2010,2011) -(2003,2004,2005)	0.11	0.41	-0.20	0.22	0.16	0.27	-0.11	-0.22	0.01	0.29	0.25	0.32
Zhou et al., 2013, Table 7 QA1 values, ΔT, °C	2010-2003	0.14	0.68	0.41	0.01	0.05	-0.07	0.42	0.23	0.61	0.29	0.30	0.28
Xia et al., 2015, Table 2, ΔT, °C	(2010,2011,2012,2013,2014)-(2003,2004)	0.18	0.28	0.07	0.26	0.28	0.23	-0.25	-0.39	-0.11	0.40	0.26	0.53
average weighted by obs. years		0.14			0.20			-0.10			0.34		
this study, simulated at TX location (ΔT), °C	(2012,2013,2014)-(2012,2013,2014)	0.48			0.65			0.22			0.60		
this study simulated at TX location, control, °C	2012,2013,2014	10.30			5.41			22.87			14.58		
this study, simulated at TX location, 0.5 MW/km^2, °C	2012,2013,2014	10.78			6.05			23.08			15.18		

		June - August						September - November					
		DAY			NIGHT			DAY			NIGHT		
Reference	Analysis Period	avg.	10:30	13:30	avg.	22:30	1:30	avg.	10:30	13:30	avg	22:30	1:30
Zhou et al., 2013, Table 7 QA1 values, ΔT, °C	(2009,2010,2011) -(2003,2004,2005)	0.17	-0.18	0.52	0.35	0.46	0.24	-0.04	-0.03	-0.04	0.40	0.43	0.37
Zhou et al., 2013, Table 7 QA1 values, ΔT, °C	2010-2003	1.52	0.84	2.20	0.67	0.70	0.64	0.12	0.18	0.05	0.47	0.59	0.35
Xia et al., 2015; Table 2, ΔT, °C	(2010,2011,2012,2013,2014)-(2003,2004)	-0.26	-0.38	-0.13	0.42	0.38	0.45	-0.02	0.05	-0.08	0.27	0.37	0.17
average weighted by obs. years		0.15			0.42			-0.01			0.35		
this study, simulated at TX location (ΔT), °C	(2012,2013,2014)-(2012,2013,2014)	0.34			0.86			0.29			0.54		
this study simulated at TX location, control, °C	2012,2013,2014	35.47			27.89			24.06			16.11		
this study, simulated at TX location, 0.5 MW/km^2, °C	2012,2013,2014	35.82			28.75			24.35			16.64		

		Annual					
		DAY			NIGHT		
Reference	Analysis Period	avg.	10:30	13:30	avg.	22:30	1:30
Zhou et al., 2013, Table 7 QA1 values, ΔT, °C	(2009,2010,2011) -(2003,2004,2005)	-0.04	-0.03	-0.04	0.25	0.28	0.22
Zhou et al., 2013; Table 7 QA1 values, ΔT, °C	2010-2003	0.49	0.42	0.56	0.26	0.31	0.20
Xia et al., 2015, Table 2, ΔT, °C	(2010,2011,2012,2013,2014)-(2003,2004)	-0.09	-0.11	-0.06	0.33	0.32	0.34
average weighted by obs. years		0.01			0.29		
this study, simulated at TX location (ΔT), °C	(2012,2013,2014)-(2012,2013,2014)	0.33			0.66		
this study simulated at TX location, control, °C	2012,2013,2014	23.17			16.00		
this study, simulated at TX location, 0.5 MW/km^2, °C	2012,2013,2014	23.51			16.66		

EXHIBIT

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(https://maps.google.com/maps?ll=41.010843,-83.069054&z=17&t=k&hl=en-US&gl=US&mapclient=apiv3)

Imagery ©2018 , DigitalGlobe, State of Ohio / OSIP, USDA Farm Service Agency

Exhibit H. Noise Impact Assessment

REPORT

NOISE IMPACT ASSESSMENT FOR REPUBLIC WIND – SENECA AND SANDUSKY COUNTY, OHIO

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12.22.2017

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gusts recorded at the four sites equipped with anemometry are listed in Table 1. Over the 15 days of monitoring, precipitation fell as rain on February 8 and February 15.[4] The exact rain periods at each site were verified from their respective audio recordings.

TABLE 1: MAXIMUM MEASURED WIND SPEEDS BY SITE

Monitoring Location	Max Wind Speed		Max Gust Speed		Average Wind Speed	
	m/s	mph	m/s	mph	m/s	mph
Agricultural Operations	9.1	20.3	12.1	27.0	1.7	3.8
Mixed Residential	7.1	15.8	11.3	25.3	1.4	3.2
North Boundary	6.8	15.2	10.8	24.2	1.3	2.9
Southern Boundary	10.3	23.1	13.6	30.4	1.6	3.5

SUMMARY OF SOUND LEVELS

The equivalent continuous sound level (L_{eq}) and tenth-percentile sound level (L_{90}) data logged at each monitoring location are plotted as time history graphs, along with the maximum 10-minute gust speed and temperature in Figures 17 through 37. (For an explanation of the sound level metrics and their use, see Appendix A, "A Primer on Sound and Noise".) Each time history graph spans one calendar week for ease of viewing. Periods that have been excluded from the averaging of sound levels due to high wind, low temperature, rain, or anomalous events, are indicated on each graph. However, the original data for those periods are still shown, using lighter colors. Results specific to each monitor location are described in the following sections.

All the monitors were within audible range of freight train passby events (and their horns at crossings). Additionally, aircraft overflights, mostly by commercial jets operating at cruise altitudes, were evident at every site. All the monitors were near dormant farm fields. As the monitoring occurred in the winter, field farming activities were not evident in the data.

Summary sound levels for the monitoring period at all sites are presented in Table 2. They include the equivalent continuous average (L_{eq}), and the 10th-percentile (L_{90}), 50th-percentile (L_{50}) and 90th-percentile (L_{10}) statistical levels for the entire period, for the daytime periods, and for the nighttime periods.[5]

The Mixed Residential monitor was the closest monitor to a residential area ("in town"). It recorded the highest average levels as a result of frequent use of the nearby Flat Rock Care facility parking lot. The Busy Roadway monitor was exposed to regular high-speed car and truck pass bys.

[4] Rain periods were identified from historical meteorology data available online Weather Underground stations KOHMONRO6 and KOHREPUB2, at http://www.wunderground.com.
[5] Daytime is defined here as the period from 7:00 AM to 10:00 PM; nighttime is defined here as the period from 10:00 PM to 7:00 AM the following day.

The quietest sites were the Southern Boundary and the Wooded Area, which were more distant from roads and areas of frequent human activity.

The relatively larger differences between equivalent continuous levels (L_{eq}) and lower tenth-percentile levels (L_{90}) at most of the sites indicate that the soundscapes are dominated by transient events resulting from human activity. Weather patterns (mostly wind) also influenced sound levels. Thus, only some of the data show a typical anthropogenic diurnal pattern, where sound levels are higher during the day and lower at night.

The OPSB precedent sound level is calculated from the arithmetic average of the site-wide nighttime equivalent average sound levels (L_{eq}) plus 5 dB. The site-wide average sound levels are shown in the last row of Table 2. Among all seven sites in the Republic project area, the average nighttime L_{eq} is 41 dB, which results in an OPSB precedent project-only sound level limit of 46 dBA $L_{eq\ 1\text{-}hr}$.

TABLE 2: SUMMARY SOUND LEVELS FROM PRE-CONSTRUCTION MONITORING

Location	Sound Level (dBA)											
	Overall				Day				Night			
	L_{eq}	L_{90}	L_{50}	L_{10}	L_{eq}	L_{90}	L_{50}	L_{10}	L_{eq}	L_{90}	L_{50}	L_{10}
Agricultural Operations	43	26	35	46	44	29	37	47	40	24	30	41
Busy Roadway	50	27	39	54	52	32	42	55	47	24	33	49
Mixed Residential	51	29	36	47	51	31	37	47	51	27	34	46
North Boundary	47	27	33	42	48	28	34	42	44	25	31	41
Rural	42	24	32	44	43	26	34	45	39	21	30	40
Southern Boundary	37	21	31	39	38	23	32	39	34	17	28	37
Wooded Area	36	23	30	38	37	25	31	39	32	21	27	35
Arithmetic Average	44	25	34	44	45	28	35	45	41	23	30	41

JACKSON
LIBERTY
PLEASANT
ADAMS
THOMPSON
LOUDON
HOPEWELL
CLINTON
SCIPIO
REED
BIG SPRING
SENECA
EDEN
BLOOM
VENICE
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3360 STR 151
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EXHIBIT

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