Wind Energy 101:

A Guidebook for South Dakota Leaders and Stakeholders

Summer 2018

APEX CLEAN ENERGY

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DAKOTA RANGE III WIND

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DAKOTA RANGE III WIND PROJECT PROFILE

LOCATION: Grant and Roberts Counties, South Dakota

TOTAL CAPACITY: 150 MW

NUMBER OF TURBINES: Up 50

ANTICIPATED START DATE OF COMMERCIAL OPERATION: 2020-2021

Apex Clean Energy has submitted a permit to the South Dakota Public Utilities Commission to construct Dakota Range Wind III, a wind energy project expected to generate up to 150 megawatts of clean, homegrown energy. Local wind data confirms that the area under consideration is ideal for a project of this size, which will produce enough safe, pollution-free energy to power tens of thousands of U.S. homes. Construction is expected to begin in 2020 and be completed in 2021.

A Major Economic Opportunity for Grant and Roberts Counties

Dakota Range Wind III will create jobs and generate an entirely new source of long-term revenue for schools, governments, and landowners. Each year, Grant and Roberts Counties can expect to receive tens of thousands in new tax revenue, respectively, with additional indirect economic benefits greatly exceeding that number.

Landowners participating in the project all receive equal per-acre payments, whether there is a turbine on the property or not. These payments will continue over the projected 30-year lifespan of the wind farm, injecting millions of dollars into the economies of Grant and Roberts Counties to support local merchants, contractors, equipment suppliers, auto dealers, and others.

Developed and constructed with private capital, the project is expected to generate millions of dollars in total taxes that are split between the different taxing authorities, including the school districts.

Local Economic Benefits

- Enough power for nearly 100,000 U.S. homes
- Hundreds of jobs and significant local spending during construction, benefiting local vendors and other businesses
- Approximately 5 full-time operations jobs
- Taxpayers protected against decommissioning costs
- 30 years of annual revenue for county, local landowners, and local schools, totaling millions of dollars

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Dakota Range III Wind, LLC

Health FAQs

Christopher Ollson, Ph.D.
Senior Environtal Health Scientist
Ollson Environmental Health Management

On May 9, 2017, Dr. Ollson delivered a presentation to the Clay County, Iowa Board of Supervisors discussing recent scientific findings regarding the relationship between wind turbines and human health. Highlights of this presentation are included in the following paragraphs.

Summary:

- Based on the findings of over 80 available peer-reviewed scientific studies, the weight of evidence shows that when sited properly, wind turbines ***do not*** cause adverse human health effects.
- South Dakota's permitting requirements provide ample protections for project area residents covering ice throw, noise, and continuation of normal farming conditions.
- Therefore, there is no reason to be concerned about undue health effects associated with Dakota Range III.

Wind Turbine Syndrome

The scientific evidence is conclusive: "There is no evidence for a set of health effects from exposure to wind turbines that could be characterized as Wind Turbine Syndrome." (Massachussets Wind Turbine Health Impact Study: Report of Independent Expert Panel, January 2012).

Wind Turbine Sound

Dakota Range III will self-regulate noise levels to participating and non-participating residences, as required to by Grant and Roberts Counties. Typically, turbines will have to be located between 750 and 1500 feet from a participating residence in order to meet noise standards. The specific distance required for any given turbine depends on the turbine model, the number of turbines, the project layout, and other site-specific conditions.

According to a comprehensive Canadian study that looked into the effects of wind turbines on human sleep patterns, there is no evidence to support the idea that turbine sound at a decibel level of 48-50 dBA causes sleep disturbance. The study tested this effect among subjects located between 820 feet and 6 miles from a turbine.

Low-frequency sound and infrasound

Infrasound is low-frequency sound that is generally undetectable by the human ear. Sound with a frequency below 20 Hz is considered infrasound. Decades of research has produced no evidence that either infrasound or low-frequency sound from wind turbines has any impact on

human health. This is because wind turbines produce infrasound and low-frequency sound at levels far below anything that might pose a health risk to people or animals.

As the Massachusetts Department of Public Health has reported, "…the weight of the evidence suggests no association between noise from wind turbines and measures of psychological distress or mental health problems."

Shadow flicker

The term "shadow flicker" refers to the shadows cast by turbine blades as they rotate in front of the sun, similar to shadows cast by trees blowing in the wind. It is not a health concern.

During cloudy or foggy days, low wind days, and during a majority of the months in a year, shadow flicker does not occur. If it does occur at a time of day where it is a nuisance, there are some remedies that typically resolve the problem such as installing heavy curtains, darkening shades, an awning, or planting trees/bushes.

Though some people worry that turbine shadow flicker could trigger seizures in photosensitive epileptic individuals, studies show that modern turbine blades spin far too slowly to trigger epileptic seizures or create any medical concerns.

Ice Throw

While it is true that ice can accumulate on turbine blades under certain conditions, it is rare for this to pose a potential threat to humans or surrounding area structures.

Sophisticated sensors on modern turbine blades automatically shut the turbines down when icing occurs to eliminate the risk of accidental ice shedding while turbines are spinning. When the icing event is over and the wind technicians are preparing to turn the turbines back on, they follow careful ramp-up protocols, which help ensure that any ice being shed from the blades drops straight to the ground like icicles or snow sliding off a roof. By slowly ramping turbines back up, operators can make sure that ice is not thrown from the blades.

With these safety protocols in place, there should be no concern that ice throw will present a risk at Dakota Range III.

Stray voltage

The presence of stray voltage is a common issue on farms across the U.S., and it is entirely unrelated to wind farms or wind turbines. In fact, modern wind turbines are engineered to operate with a three-phase electrical system, which makes it physically impossible for wind turbines to produce stray voltage. That said, should stay voltage from any source ever be detected on a property, or if animals are seen to exhibit avoidance behavior that is thought to be associated with stray voltage (such as not drinking from a particular water trough), the problem can be easily traced and rectified.

Crop dusting

Dakota Range III will work with local aerial spray operators to ensure safe operations during times when crop dusters are working in the area. Because crop dusting often does not occur

during the times when the turbines are in peak production – when the wind is blowing heavily – this is generally not an issue that poses a problem to either the crop duster or the wind farm operator.

“Beam paths,” cell signals, and TV reception

Dakota Range III will conduct a study to locate and track registered and non-registered cell towers, antennae, microwave beam paths, and 911 signals, and it will take these findings into consideration in the project design. A copy of the final study will be included in our permit application and will be available to the public.

Dakota Range III does not anticipate any interference to TV reception in the project area, but should interference occur, the facility will work to remedy the disturbance immediately.

Turbine manufacturer safety guildelines

Many turbine manufacturers have recommended safety protocols designed for the rare event when a turbine is not operating normally, such as during a fire. These guidelines recommend certain practices for managing the site and minimizing risk to personnel working on the scene.

If a turbine at Dakota Range III were ever experiencing this type of unusual situation, Dakota Range III staff and local emergency responders would direct citizens and personnel to stay outside of the affected area to ensure their safety and the safety of those working to address the issue.

Dakota Range III Operations and Maintenance staff will undergo safety training several times per year, and local emergency responders will be included in training exercises at least once per year.

Environment FAQs

Dave Phillips
Director of Wildlife and Environment
Apex Clean Energy

Apex Clean Energy devotes considerable time and attention to understanding and minimizing any potential impact our projects may have on the local environment. This analysis considers wildlife, wetlands, cultural resources, avian species, and more. We also carefully consider the presence of eagles in a project area to ensure that we minimize the risk to eagles. There is a very low risk of eagle mortality from a wind farm when it is properly designed.

Bald Eagles

Bald eagles are an incredible and resilient bird. Nationally, there are over 50,000 wind turbines operating across the country today, and there have only been 21 known bald eagle deaths.

Dakota Range III has studied the known eagle nests and eagle flight patterns in the project area, and it is taking this data into consideration for our project design and layout.

How will the wind farm impact local deer populations and hunting?

Dakota Range III will have no impact on local deer and waterfowl populations or on hunting. Just as deer and waterfowl adapt to the construction of new homes, buildings, and other developments within their habitat, these populations become accustomed to wind farms.

Will the wind farm be harmful to birds and bats?

Apex works closely with state and federal environmental agencies to minimize avian and bat impacts using extensive study and responsible siting practices. Wind energy projects are far from the most dangerous man-made threat to birds and bats. Housecats, buildings, cars, power lines, and radio and cell phone towers pose much greater threats to birds and bats than wind turbines.

Economic FAQs

Will Dakota Range III raise my electric bill?

The electricity produced by Dakota Range III should help stabilize and reduce the price of electricity within the MISO market area.

Because eastern South Dakota is part of the MISO regional transmission organization, all MISO ratepayers will benefit from having stable and low production cost energy from wind added to the grid.

What economic impacts will the project make locally?

Dakota Range III will represent a significant capital investment in eastern South Dakota, with the potential of injecting millions of dollars into Grant and Roberts Counties.

The project will also create and sustain jobs. The initial construction phase will require more than 150 skilled laborers, and will result in local purchasing of materials and services. After construction, the project will create an immediate need for about 15 turbine technicians to managing ongoing operations and maintenance. “Turbine technician” was recently named the fastest growing profession in the United States by the Department of Labor Statistics.

Will the federal government subsidize the project?

Dakota Range III will be built on private land using private investments. No federal subsidies or local tax dollars will be used to supplement the up front cost of the project. Once built, the federal government offers a Production Tax Credit (PTC) to qualifying wind energy projects. This credit is not a grant or a cash payment. On the contrary, it only decreases the taxes owed by the project’s owners, based on the amount of electricity the project actually produces. Though the PTC will be fully phased out by 2020, the credit exists today to help support American wind energy production, which provides a fixed rate, low cost source of electricity and greater energy security for our nation.

Will the project affect my property values?

There are many reasons why acreage near a wind farm may or may not sell. Therefore, it is important for researchers to study this question in a manner that allows them to isolate variables to focus only on wind farm presence. The most extensive peer-reviewed study to date on property transactions near wind farms was conducted by the Lawrence Berkeley National Laboratory (LBNL) in 2013. In this study, researchers analyzed 51,276 home sales near 67 wind farms in 27 counties across nine U.S. states and found no statistical evidence that home values near turbines are affected before, during, or after construction. You can read the full study here.

Furthermore, the most robust studies on property value impacts from wind energy facilities show that wind farms often spur economic development in a community, increase enrollment in local schools, provide funding for local services, and increase participating farm values due to their stable income streams.

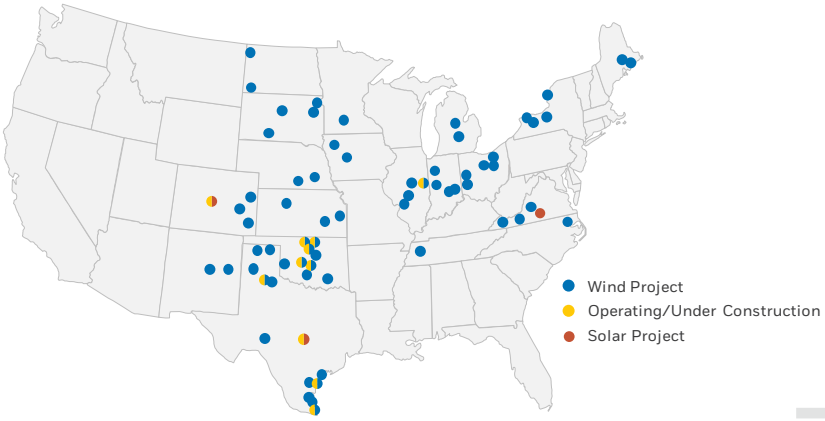
Apex Clean Energy

Accelerating the Shift to Clean Electricity

About Apex

Apex is a renewable energy company that is uniquely well-positioned to deliver large-scale clean energy solutions to markets across the country. Our mission is to accelerate the shift to clean energy.

$4 billion of clean energy opportunity created to date



Positioned to Bring Capacity Online Quickly

We are purpose-built to deliver clean energy solutions throughout the project life cycle, including site origination, development, financing, turnkey construction management, and long-term asset management.

With transmission applications for approximately 10 gigawatts of clean energy in key markets, Apex is strategically placed to build out our portfolio in the years to come.

More than 14,000 MW currently under development

Bringing Clean Energy Resources to Market

We deliver turnkey wind or solar facilities to investors while typically retaining an ownership interest and providing long-term asset management services.

We have a dozen wind and solar facilities operating in Illinois, Texas, and Oklahoma. These projects represent a total capital investment of more than $3 billion. Operating assets under management have grown to approximately 1 GW.

Over 3 GW financed and 2 GW constructed

We work with such companies and utilities as Southern Power, IKEA, AEP, Steelcase, Xcel, Alliant, and others. Our facilities offer competitive power prices, steady returns, and the ability to hedge inflation and carbon risk.

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apexcleanenergy.com

MaROUS & COMPANY

April 6, 2018

Apex Clean Energy, Inc.
8665 Hudson Boulevard North - Suite 110
Lake Elmo, Minnesota 55402

Attention: Mr. Mark Mauersberger, Senior Development Manager

Subject: Market Impact Analysis
Proposed Dakota Range Wind Project
Codington County and Grant County, South Dakota

Dear Mr. Mauersberger,

In accordance with your request, the proposal to develop a wind farm in Codington County and Grant County, South Dakota, has been analyzed and this market impact analysis has been prepared.

MaRous & Company has conducted similar market impact studies for a variety of clients and for a number of different proposed developments over the last 30 years. Clients have ranged from municipalities, counties, and school districts, to corporations, developers, and citizen's groups. The types of proposals analyzed include: commercial developments such as shopping centers and big-box retail facilities; religious facilities such as mosques and mega-churches; residential developments such as high-density multifamily and congregate-care buildings and large single-family subdivisions; recreational uses such as skate parks and lighted high school athletic fields; and industrial uses such as waste transfer stations, land-fills, and quarries. We also have analyzed the impact of high-tension electric wires on adjacent residential uses. Energy-related projects include a number of proposed natural gas-fired electric plants in various locations, and the Grand Ridge V and Otter Creek wind farms, in LaSalle County, the Pleasant Ridge Wind Farm, in Livingston County, the Walnut Ridge Wind Farm, in Bureau County, the McLean County Wind Farm, in McLean County, the Twin Forks Wind Farm, in Macon County, all in Illinois; the Freeborn County Wind Farm, in Freeborn County, Minnesota; the Ida II Wind Farm, in Ida County, the Palo Alto County Wind Farm, in Palo Alto County, both in Iowa; the Orangeville Wind Farm, in Wyoming County, New York; the Dorchester County Solar Farms, in Dorchester County, Maryland; and the Badger Hollow Solar Farm, in Iowa County, Wisconsin. In addition, we are in the process of completing market impact studies for multiple wind projects in South Dakota.

In addition to this experience, MaRous & Company has appraised a variety of properties in the large market area of the proposed project in South Dakota, in North Dakota, in Iowa, and in Minnesota in the last 3 years, including: industrial facilities, food processing plants, and warehouse and distribution facilities ranging in size from 50,000 to 1,000,000 square feet, and more than 20 major retail facilities.

Mr. Mark Mauersberger
Proposed Dakota Range Wind Project
April 6, 2018

Purpose and Intended Use of the Study

The purpose of this appraisal assignment is to analyze the potential impact, if any, on the value of the surrounding rural residential and agricultural properties due to the development of the proposed wind farm. Specifically, this study is designed to address the question of whether the development of the proposed wind farm will have an effect on the value of residential uses and/or agricultural land in proximity to the turbines. Any other use or user of this report is considered to be unintended.

Executive Summary

As a result of the market impact analysis undertaken, I concluded that there is no market data indicating the Project will have a negative impact on either rural residential or agricultural property values in the surrounding area. Further, market data from South Dakota, as well as other states, supports the conclusion that the Project will not have a negative impact on rural residential or agricultural property values in the surrounding area. Finally, for agricultural properties that host turbines, the additional income from the wind lease may increase the value and marketability of those properties. These conclusions are based on the following:

- The proposed use will meet or exceed all the required development and operating standards;
- Controls, such as setbacks and noise limits, are in place to insure on-going compliance;
- There are significant financial benefits to the local economy and to the local taxing bodies from the development of the proposed wind farm;
- The proposed wind farm will create well-paid jobs in the area which will benefit overall market demand;
- An analysis of recent residential sales proximate to existing wind farms, which includes residential sales within three to five times turbine tip height, did not support any finding that proximity to a wind turbine had any impact on property values;
- An analysis of agricultural land values in the area and in other areas of the state with wind farms did not support any finding that the agricultural land values are negatively impacted by the proximity to wind turbines;
- Studies indicate that wind turbine leases add value to participant land owner's agricultural land;
- A survey of County Assessors in six South Dakota counties in which wind farms are located concluded that there was no market evidence to support a negative impact upon residential property values as a result of the development of and the proximity to a wind farm, and that there were no reductions in assessed valuations;
- A survey of County Assessors in eight Minnesota counties in which wind farms are located concluded that there was no market evidence to support a negative impact upon residential property values as a result of the development of and the proximity to a wind farm, and that there were no reductions in assessed valuations;

- A survey of County Assessors in 26 Iowa counties in which wind farms are located concluded that there was no market evidence to support a negative impact upon residential property values as a result of the development of and the proximity to a wind farm, and that there were no reductions in assessed valuations; and
- A survey of County Assessors in 18 Illinois counties in which wind farms are located concluded that there was no market evidence to support a negative impact upon residential property values as a result of the development of and the proximity to a wind farm, and that there were no reductions in assessed valuations.

Definition of Market Value

When discussing market value, the following definition is used:

> The most probable price a property should bring in a competitive and open market under all conditions requisite to a fair sale, the buyer and seller each acting prudently and knowledgeably, and assuming the price is not affected by undue stimulus. Implicit in this definition is the consummation of a sale as of a specified date and the passing of title from seller to buyer under conditions whereby:
>
> - Buyer and seller are typically motivated;
> - Both parties are well informed or well advised, and acting in what they consider their own best interests;
> - A reasonable time is allowed for exposure in the open market;
> - Payment is made in terms of cash in U.S. dollars or in terms of financial arrangements comparable thereto; and
> - The price represents the normal consideration for the property sold unaffected by special or creative financing or sales concessions granted by anyone associated with the sale.[1]

Scope of Work and Reporting Process

Information was gathered concerning the real estate market generally and the market of the area surrounding the proposed conditional use specifically. The uses in the surrounding area were considered. The following summarizes the actions taken:

- Review of the Codington County Zoning Ordinance Chapter 5.22 and other public documents;
- Review of the Grant County Zoning Ordinance 2004-1 Chapter 11-2 and other public documents;

1 *(12 C.F.R. Part 34.42(g); 55 Federal Register 34696, August 24, 1990, as amended at 57 Federal Register 12202, April 9, 1992; 59 Federal Register 29499, June 7, 1994)*

- Review of the preliminary information for the proposed wind farm from Apex Clean Energy, Inc.,;
- Review of the *Application to the South Dakota Public Utilities Commission for a Facility Permit* for the proposed wind farm from Dakota Range I, LLC and Dakota Range II, LLC, including associated Appendices ;
- Review of the demographics in the area of the proposed wind farm, based on 2017 census data;
- Data on the general market area, or the geographical area where people buy goods or services, of the proposed wind farm, and on the other areas in South Dakota and/or Codington and Grant counties in which existing wind farms are located;
- Data on the market for single-family houses in the immediate area of the proposed wind farm and from other areas in the county from public sources, from the Codington County and Grant County public records, and public records from eight other counties in South Dakota[2];
- Local real estate professionals were interviewed concerning recent sales in the area, local market conditions, and the impact of wind turbines on property values in the area;
- Properties used for development of the matched pairs were physically inspected on the exterior, and photographs of the interiors were reviewed where available;
- Inspections were performed of the project area and the areas in nearby counties with existing wind farms by Michael S. MaRous and Joseph M. MaRous on February 18-19, 2018. As well as inspections of nearby Deuel County by Michael S. MaRous on October 4-5, 2017.

This document is considered to conform to the requirements of the *Uniform Standards of Professional Appraisal Practice and Advisory Opinions* (USPAP). This letter is a brief recapitulation of the appraisal data, analyses, and conclusions; additional supporting documentation is retained in the MaRous and Company office file. There are no extraordinary assumptions or hypothetical conditions included in the market study.

In order to form a judgment concerning the potential impact, if any, on the value of the surrounding residential and agricultural properties of the proposed wind farm, I have considered the following:

- The character and the value of the residential and agricultural properties in the general area of the proposed wind farm;
- Agricultural land values in Codington County, Grant County, and in other South Dakota counties in which wind farms are located;
- Market trends for both residential and agricultural land up to the past 5 years;
- The economic impact on the larger community by the approval of the conditional use as proposed; and
- The impact on the value of the surrounding residential and agricultural properties by the approval of the proposed wind farm.

2 Deuel County, Day County, Clark County, Aurora County, Brookings County, Charles Mix County, Hyde County, and Jerauld County

Description of Area and Proposed Development

Area Analysis

Codington County and Grant County are located in the Northeast region of the state of South Dakota. The 2017 population for Codington County was estimated to be 28,572 persons, up from 27,227 in 2010. This population is situated in approximately 12,119 households as of 2017.[3] The median household income was estimated to be $50,501. Of the total approximately 13,145 housing units in the county, 1,026 or approximately 7.8 percent are vacant. The median single-family house value was $164,097.

The 2017 population for Grant County was estimated to be 7,237 persons, down from 7,356 in 2010. This population is situated in approximately 3,031 households as of 2017. The median household income was estimated to be $52,346. Of the total approximately 3,526 housing units in the county, 495 or approximately 14 percent are vacant. The median single-family house value was $126,829.

The total population directly within the footprint of the project is reported to be fewer than 1,000 persons, according to Apex's on-site supervisor, David Lau.

The unemployment rate in Codington County as of 2017 was 1.3 percent, and the median weekly household wage in 2017 was $971. The unemployment rate in Grant County as of 2017 was 1.9 percent, and the median weekly household wage in 2017 was $1,006.

The largest city in the northeast corner of the state is Watertown, with 22,172 persons, and it is approximately 15 miles south of the project's southern border. Watertown is also the Codington County Seat. Milbank is the largest city in Grant County, with 3,203 persons, and it is approximately 17 miles east of the project's eastern border. Milbank is also the Grant County Seat.

The proposed wind farm is located on the border of Codington County and Grant County, and will encompass the townships; Leola and Germantown, in Codington County; and, Lura and Mazeppa, in Grant County. A copy of a map of the proposed footprint of the wind farm is located in the addenda to this report.

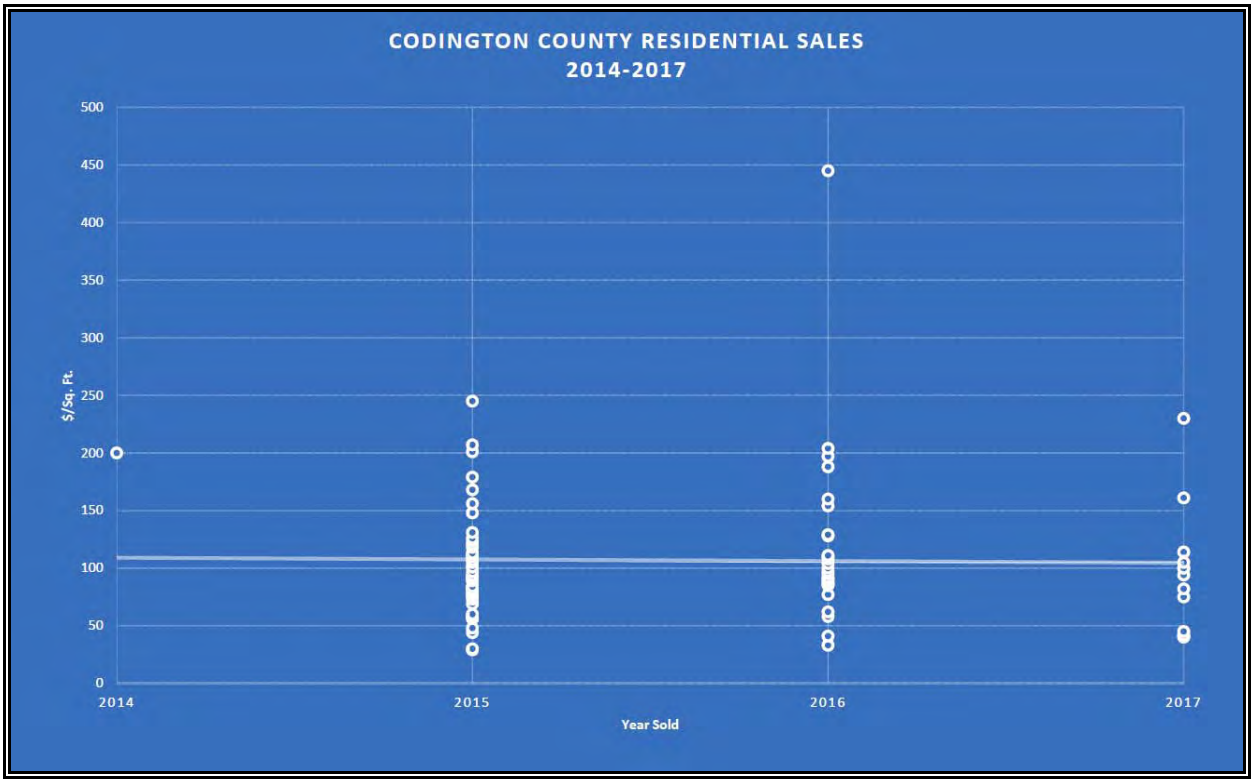
3 The demographic data included in this section of the report are taken from Site-to-do-Business, https://www.stdb.com. Unless otherwise indicated, the data is from 2017.

Like the majority of South Dakota, this area is primarily rural in nature. In addition to farms, there are single-family houses situated on either smaller lots or larger farmsteads. The following table summarizes recent sales of these types of residences in the general area of the proposed Dakota Range Wind Project. A map illustrating the location of each of these sales is included in the addenda to this market impact study.

RECENT SINGLE-FAMILY RESIDENTIAL SALES SUMMARY
IN THE AREA OF PROPOSED DAKOTA RANGE WIND PROJECT

No.	Location	Sale Price	Sale Date	Site Size (Acres)	Year Built	Building Size Sq. Ft.	Sale Price Per Sq. Ft. of Bldg. Area Incl. Land
1	101 2nd Ave. Waverly, South Dakota	$66,800	8/16	0.38	1900	2,016	$33.13
2	46274 154th St. South Shore, South Dakota	$135,000	9/15	5.28	1953	1,516	$89.05
3	45624 165th St. Watertown, South Dakota	$142,500	12/17	7.57	N/A	3,200	$44.53
4	14419 468th Ave. Twin Brooks, South Dakota	$145,000	9/15	5.25	1974	2,316	$62.61
5	47724 144th St. Milbank, South Dakota	$349,900	8/16	10.00	2002	3,224	$108.53

A sample size of 90 residential sales throughout Codington County from year 2014 to 2017 also was compiled and was analyzed. Codington County was chosen to represent the market in this overall analysis due to the county's much larger population compared to that of Grant County. The sales were compiled from public sources and were broken down by price per square foot and year sold.



Noting the trend line, indicated in the data in the charts above, the overall residential market has been declining slowly throughout the past 4 years

Proposed Project

The proposed project currently plans to generate approximately 300 megawatts from up to 72 wind turbines. Construction will begin in 2019 and is expected to be online in 2021. The turbines will Vestas V136-4.2MW that have a capacity of 4.2 megawatts each, with a total capacity of 302.4 megawatts, and will be approximately 492 feet to the top of the blade tip. The proposed wind farm is split between the border of Codington County and Grant County, South Dakota, covering approximately 44,500 acres of land. The proposed project footprint is described in a map in the addenda to this market study. All turbines will be new, and none will be experimental or prototype equipment. The turbine specifications are described in the following table.

Manufacturer	Model	Diameter	Height	Capacity
Vestas	V136-4.2MW	136 m (466')	150 m (492')	4.2 MW

The total project cost is estimated to be $380,000,000 with a possible fluctuation of +/- 20 percent. Ancillary construction includes 16-foot to 36-foot wide gravel-covered access roads, a wind electrical collection system with 34.5 kV lines trenched 30 inches below ground, a collector substation that will increase voltage from 34.5 kV to 345 kV, an interconnection switching station adjacent to the Big Stone South-to-Ellendale 345 kV line, five permanent meteorological towers, a “SCADA” or Supervisory Control and Data Acquisition system, and an operations and maintenance building. Agreements with Codington and Grant counties and with townships impacted will identify roads to be used, and will require repairing of any damage caused by the project. The Codington and Grant counties’ setback standards of 110 percent of tip height or 1,000 feet, from nonparticipating residences and public roads, and 500 feet, from participating residences, will be met with the closest turbine to an residence at greater than 1,300 feet away. Dakota Range Wind Project has also agreed to a voluntary setback of 2 miles from the shoreline of Punished Woman’s Lake, which will be met with the closest turbine to be located approximately 2.75 miles away from the nearest residence. Both Codington County and Grant County also require the noise level at any residence, business, or government building to not exceed 50 dBA, at the property line for Codington County and at the specific structure for Grant County. The project will also implement a voluntary maximum annual shadow flicker level for nonparticipants of 30 hours per year or less. Per information reviewed these requirements will be met by the project.

Project Benefits

In accordance with the State of South Dakota's property assessment requirements for wind turbines, local real estate tax benefits for the entire Dakota Range Wind Project are estimated to be greater than $1,000,000 per year if the full capacity of the project is constructed. The estimated breakdown of local tax allocation is described in the following table.

	Yearly
School District Tax Revenue	$505,000
Township Tax Revenue	$151,000
County Tax Revenue	$360,000
Total Local Tax	$1,016,000

Annual payments to participating landowners and good-neighbor agreements will add significantly to the local economy. Prior to construction, participating landowners will have received more than $500,000 in development payments. The project has acquired approximately 45 participating landowners within the project boundary of Codington County. As seen in the table above, the local community and school districts will receive sizable amounts of funding from the project taxes. Additionally, the project will generate approximately 300 temporary construction jobs and is expected to create approximately 10 permanent jobs when fully operational.

Further direct and indirect impacts from the construction of the project, including permits and construction jobs, as well as "induced impacts" from the increase in household spending also are anticipated.

Market Impact Analysis

A market impact analysis is undertaken to develop an opinion as to whether the proposed wind farm will have an effect on the value of residential uses and/or agricultural land in proximity to the turbines. This

analysis includes:

- A matched pair analyzing the impact on value of residential properties proximate to a wind farm in Brookings County, South Dakota, as well as matched pairs developed in counties with similar demographics, land use, and economic characteristics, just east of this area in Minnesota, and in similarly rural counties in Iowa and Illinois;
- The value of agricultural land in Codington and Grant counties and in other counties with existing wind farms;
- Interviews of local real estate professionals;
- The results of a survey of assessors in South Dakota, Iowa, Minnesota, and Illinois with existing wind farms in their respective jurisdictions; and
- The results of several academic and peer-reviewed studies of the impact of wind turbines on residential property values.

Matched Pair Analysis

A matched pair analysis is a methodology which analyzes the importance of a selected characteristic, in this instance proximity to a wind turbine, to the value of a property.[4] This technique compares the sale of a property in proximity to the selected characteristic to the sale of a similar property in the same market area and under similar market conditions but without the proximity to the selected characteristic.

It is difficult to find properties that are identical except for proximity to a wind turbine, and which also occurred under substantially similar market conditions, especially in rural areas. Many sales in the area are also conducted privately from family member to family member, or passed down from generation to generation, causing there to be a lack of sale information or, at most times, do not sell at full value. The research throughout Codington County and Grant County indicated that there were no sales proximate to wind turbines in either county. The only sale found in South Dakota that is located in the general market area of a wind farm, based on data research from the entire state, was a residence within four miles to the Buffalo Ridge Wind Farms in nearby Brookings County. This sale provided some basis for a comparison analysis due to the similar demographics and land use of the surrounding area. However, the sale is not close enough to a wind turbine to serve as a proximate sale. Thus, while a paired sales analysis is

4 See the discussion "Paired Sales Analysis" and "Sale/Resale Analysis" in Bell, Randall, MAI, *Real Estate Damages, Applied Economics and Detrimental Conditions, Second Edition*, Appraisal Institute, 2008, pages 25-27. The ideal is to review a sale and resale of a property in proximity to a selected characteristic, to compare it to a sale and resale of a similar property without such proximity, and to then analyze whether the proximity to the selected characteristic influenced the change in value. However, in rural areas it usually is not possible to find data for this type of "pure pair" analysis.

provided, it is not considered a proximate and not proximate matched pair for purposes of determining potential impact on value due to proximity to a wind farm.

Due to the lack of sales data proximate to wind turbines in South Dakota, data from nearby states that have a stronger presence of wind turbines, similar demographics, similar economics, and similar agricultural characteristics, have been analyzed.

Details of the sales included in this analysis are retained in my office files; maps in the addenda to this report illustrate the location of the properties. Unless otherwise indicated, none of the purchasers in these transactions appear to own any other property in proximity, and none of the transactions appear to have a wind turbine lease associated with the property.

Brookings County No. 1 - Residences Not Proximate to Wind Turbines

The Buffalo Ridge Wind Farms are located in Brookings County in the East-Central region of South Dakota and consists of 129 turbines that began commercial operations in 2009. Phases I and II are both located primarily in Brookings County. Phase I came online in 2009 with 24 turbines generating approximately 50.4 MW of power. Phase II was much larger, following the first phase the next year in 2010 with 105 turbines generating approximately 210 MW of power. A property located at 19937 473rd Avenue, White, South Dakota, sold in May 2015 for $169,500. The sale previously sold in July 2014 for $121,640. The nearest turbine is approximately 4 miles to the east of this property.

This property is compared with a similar property located at 5705 Rathum Loop, Brookings, South Dakota, that sold in June 2015, which is not located proximate to any wind turbines within 10 miles. The salient details of these two properties are summarized in the table below.

The following aerial map illustrates the relationship of the 473rd Avenue property to the closest wind turbines.

BROOKINGS COUNTY NO. 1

	1A - Within 4 Miles to a Wind Turbine	1B - Over 10 Miles From a Wind Turbine
Address	19937 473rd Ave. White, SD 57276	5705 Rathum Loop Brookings, SD 57006
Distance from Turbine	4 Miles (nearest)	13 Miles
Sale Date	May 20, 2015	June 5, 2015
Sale Price	$169,500	$142,000
Sale Price/Sq. Ft. (A.G.)	$61.68	$68.33
Year Built	1908	1973
Building Size	2,748 sq. ft.	2,078 sq. ft.
Lot Size	14.8 acres	0.49 acre
Style	Two-story; frame (vinyl) 5 bdrms., 2.0 ba.	One-story; frame (vinyl) 9 rms., 3 bdrms.
Basement	Full, unfinished	Crawlspace
Utilities	Central air; Electric & forced-air heat; Well & septic	Central air; Forced-air heat; Well & septic
Other	Large detached barn; Shed, utility buildings	1-car attached garage 3-car detached garage Patio, deck, utility buildings

19937 473rd Avenue

5705 Rathum Loop

Although the 473rd Avenue property is a two-story farmstead, and the Rathum Loop property is technically a ranch-style house, both properties have similar amenities, and are situated in similar exterior surroundings. An upward adjustment for the superior building size of Rathum Loop is required. In the case of the 473rd Avenue property, there is a large detached barn, a shed, and utility buildings. The property is also in a very rural area of the county. In the case of the Rathum Loop property, there are two garages and a multiple utility buildings. The Rathum Loop building is of relatively newer construction, yet is still approximately 50 years old, compared to the 473rd Avenue property that is closer to 100 years old; both properties are considered to be in normal condition by the Brookings County Assessor. An upward adjustment is made for the basement area of Rathum Loop. The 473rd Avenue property is situated on a much larger lot than that of the Rathum Loop property requiring an upward adjustment; however, both lots are surrounded by agricultural and pasture land, which mitigates the size differential to some degree.

ADJUSTMENT GRID

Sale No.	Location	Sale Date	Year Built	Building Size	Lot Size	Style	Basement	Utilities	Out-Buildings
1B	5705 Rathum Loop Brookings, SD 57006	○	-	+	+	+	+	○	○

\+ Positive adjustment based on comparable being inferior in comparison to property #1A
\- Negative adjustment based on comparable being superior in comparison to property #1A
○ No adjustment necessary

When adjustments noted in the above table for newer construction, yet smaller size of the Rathum Loop property, the lower price of the 473rd property is justified by the factors noted in the above description.

Matched Pair Analysis- Minnesota, Iowa, and Illinois Counties

In addition to analyzing sales in the subject project area, I have researched sales in proximity to several existing wind farms in rural areas of Minnesota, Iowa, and Illinois, to determine whether residential property values in these areas were impacted by their locations in relation to wind farms. The following are the results of the most recent of these studies.

As with the Brookings County research, details of these sales are retained in my office files; maps in the addenda to this report illustrate the location of these matched pairs. Unless otherwise indicated, none of the purchasers in these transactions appear to own any other property in proximity, and none of the transactions appear to have a wind turbine lease associated with the property.

MINNESOTA MATCHED PAIR STUDY
Freeborn County Matched Pair No. 1

Freeborn County, Minnesota, is located north adjacent to central Iowa. Matched Pair #1 considers the sale of a property in the footprint of the Bent Tree Wind Farm in Freeborn County, which has been operational since February 2011. A house located at 69525 305th Street, Hartland, sold in March 2016. This house is approximately 2,375 feet from the nearest turbine; there are several turbines located to the south and southeast.

This sale is compared with a similar property located at 70308 240th Street, Albert Lea, that sold in May 2016. Although it is not located near wind turbines, several are visible from the house, but are more than 1.5 miles away. The location is very rural in nature. Market conditions are considered to be substantially similar at the dates of sale. The salient details of these two properties are summarized in the table below.

FREEBORN COUNTY MATCHED PAIR NO. 1

	1A - PROXIMATE TO A WIND TURBINE	1B - NOT PROXIMATE TO A WIND TURBINE
Address	69525 305th St. Hartland, MN 56042	70308 240th St. Albert Lea, MN 56007
Ft. from Turbine	2,375 (nearest)	NA
Sale Date	March 31, 2016	May 16, 2016
Sale Price	$89,000	$100,000*
Sale Price/Sq. Ft. (A.G.)	$57.12	$61.80
Year Built	1880	1925
Building Size	1,558 sq. ft.	1,618 sq. ft.
Lot Size	5.51 acres	4.01 acres
Style	Farm house; frame (vinyl) 3 or 4 bdrms., 2.0 ba.	Farm house; frame (vinyl) 3 bdrms., 2.0 ba.
Basement	Full, unfinished	Partial, unfinished
Utilities	No central air; propane heat; Well & septic	Central air; natural gas heat; Well & septic
Other	2-car detached garage Deck, outbuildings	2.5-car detached garage Deck, outbuildings

* This is the sale price reported by the Assessor.

69525 305th Street

70308 240th Street

Both properties are older, farm-house style and of frame construction with vinyl siding. They are somewhat similar in size. However, the 240th Street house is superior to the 305th Street house in condition; it is classified by the Assessor as being in better condition, and is described in the online listing as having been renovated recently. The 305th Street house does not have central air conditioning, and does not have natural gas available; however, the 240th Street house has both. Both the central air conditioning and the availability of natural gas are considered superior factors for 240th Street requiring a downward adjustment. An upward adjustment for the full basement of 305th Street compared to the partial basement of 240th Street.

The house on 240th Street has a site size approximately 1.5 acres smaller than that of the 305th Street house. However, this is more than offset by the location on a hard-surface road, as well as the proximity to Interstate 90 access and to the city of Albert Lea.

ADJUSTMENT GRID

SALE NO.	LOCATION	SALE DATE	YEAR BUILT	BUILDING SIZE	LOT SIZE	STYLE	BASEMENT	UTILITIES	OUT-BUILDINGS
1B	70308 240th St. Albert Lea, MN 56007	○	-	○	○	○	+	-	○

\+ Positive adjustment based on comparable being inferior in comparison to property #1A
\- Negative adjustment based on comparable being superior in comparison to property #1A
○ No adjustment necessary

When the adjustments noted above for superior condition, air conditioning, and the availability of natural gas are made to the sale price of the 240th Street house, the two properties have essentially the same per square foot value. In other words, the higher per foot sale price for the 240th Street house is justified by its superior condition and amenities. Thus, the difference in the sale price does not support the conclusion that proximity to the wind turbines had a negative impact on the sale price of the property at 69525 305th Street.

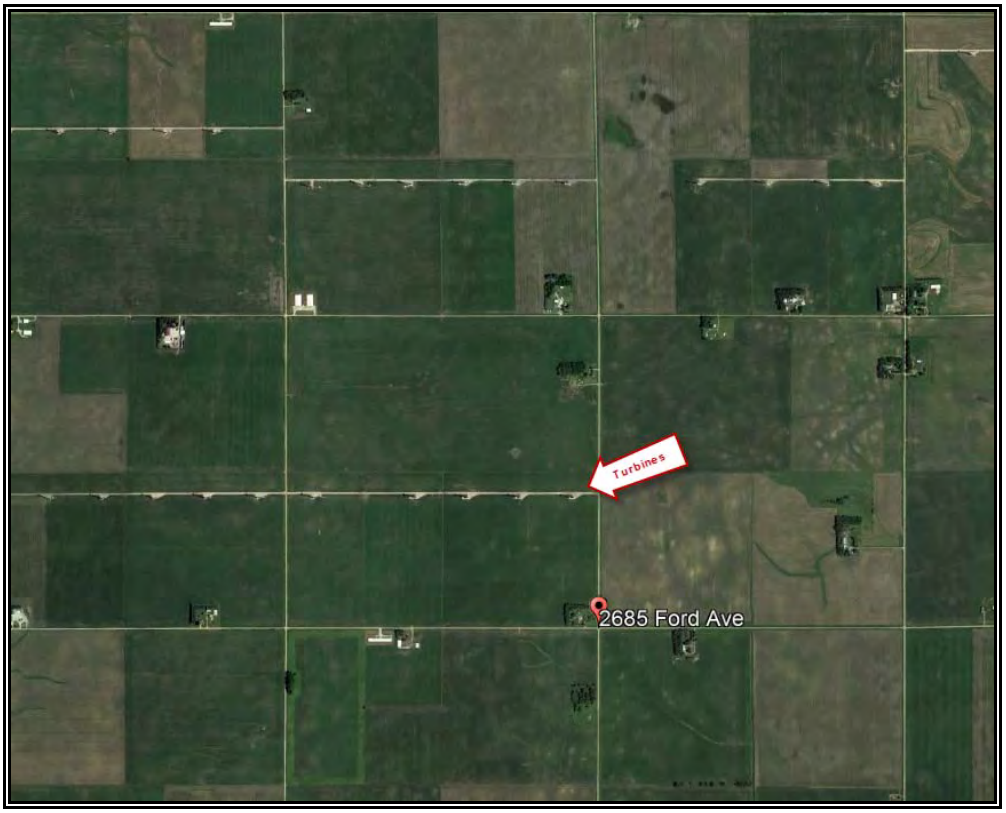
IOWA MATCHED PAIR STUDY

Hancock County is located in northern Iowa and is a largely rural county, primarily agricultural in nature. The county has two areas of wind turbines, the Hancock County wind farm in the southeast portion of Hancock County and the Crystal Lake Energy Center in the northwest portion of Hancock County.

Hancock County Matched Pair No. 1

Crystal Lake I Wind Farm is located in Hancock County in north central Iowa and consists of 100 turbines that began commercial operations in 2008. Phases II and III were located primarily in Winnebago County; which added another 80 and 44 turbines, respectively, and began operations in approximately 2009. A property located at 2685 Ford Avenue, Britt, sold in May 2016, for $155,400. The sale previously sold in October 2012 for $150,000. The nearest turbine is approximately 2,000 feet to the north and west of this property.

The following aerial map illustrates the relationship of the Ford Avenue property to the closest wind turbines.



This property is compared with a similar property located at 2855 Taft Avenue that sold in December 2014, and is not located proximate to any wind turbines. Market conditions between December 2014 and May 2016 are considered to have been stable in this area of Iowa. The salient details of these two properties are summarized in the table below.

HANCOCK COUNTY MATCHED PAIR NO. 1

	1A - PROXIMATE TO A WIND TURBINE	1B - NOT PROXIMATE TO A WIND TURBINE
Address	2685 Ford Ave. Britt, IA 50423	2855 Taft Ave. Garner, IA 50438
Ft. from Turbine	2,020 (nearest)	NA
Sale Date	May 20, 2016	December 22, 2014
Sale Price	$155,400	$190,000
Sale Price/Sq. Ft. (A.G.)	$81.62	$94.25
Year Built	1959	1975
Building Size	1,904 sq. ft.	2,016 sq. ft.
Lot Size	2.08 acres	1.22 acres.
Style	Ranch; frame (metal siding) 3 bdrms., 2.0 ba.	Split level; frame 3 bdrms., 2.0 ba.
Basement	Full, finished	None; slab
Utilities	Central air; Well & septic	In-wall air; Electric heat Well & septic
Other	2-car attached garage; 1-car detached garage; Patio, porch, shed	2.5-car attached garage; Patio, deck, utility buildings

2685 Ford Avenue

2855 Taft Avenue

Although the Ford Avenue property technically is a ranch-style house, and the Taft Avenue property is a split-level-style house, both properties have lower levels that comprise a family room and an additional room. An upward adjustment for the superior market condition of Ford Avenue is made. In the case of the Ford Avenue property, the additional lower-level room is a kitchen, and the basement square footage is not included in the building size and an upward adjustment is made for this feature. In the case of the Taft Avenue property, the lower level is not below grade, and the area, which includes a family room and a bedroom, is included in the square footage. The Taft Avenue building is of newer construction and a downward adjustment is made; however, the Ford Avenue property has been adequately maintained; both properties are considered to be in normal condition by the Hancock County Assessor. An upward adjustment is made for the central air of Ford Avenue compared to the in-wall air of Taft Avenue. The Ford Avenue property is situated on a larger lot than that of the Taft Avenue property; however, both lots have wooded areas along the rear property line, which mitigates the size differential to a large degree.

ADJUSTMENT GRID

Sale No.	Location	Sale Date	Year Built	Building Size	Lot Size	Style	Basement	Utilities	Out-Buildings
1B	2855 Taft Ave. Garner, IA 50438	+	-	○	○	○	+	+	○

\+ Positive adjustment based on comparable being inferior in comparison to property #1A
\- Negative adjustment based on comparable being superior in comparison to property #1A
○ No adjustment necessary

When the adjustments noted above for newer construction and the superior above-grade location of the second family room are made to the sale price of the Taft Avenue house, the two properties have essentially the same per square foot value. In other words, the higher per foot sales price for the Taft Avenue house is justified by its superior condition and location. Thus, the difference in the sales price does not support the conclusion that proximity to the wind turbines had a negative impact on the value of the Ford Avenue property.

Mr. Mark Mauersberger
Proposed Dakota Range Wind Project
April 6, 2018

ILLINOIS MATCHED PAIR STUDY

Macon County Matched Pair No. 1

Matched Pair #1 considers the recent sale of a property located at 8873 North Glasgow Road, Warrensburg, that is 1,855 feet from the nearest wind turbine located within the subject, Twin Forks Wind Farm, with approximately four additional turbines visible from the property to the north and west.

MACON COUNTY MATCHED PAIRS NO. 1

	1A PROXIMATE TO A WIND TURBINE	1A PRIOR SALE	1C NOT PROXIMATE TO A WIND TURBINE
Address	8873 North Glasgow Road Warrensburg, IL 62573	8873 North Glasgow Road Warrensburg, IL 62573	1511 Hunters View Drive Mount Zion, Illinois 62549
Ft. from Turbine	1,855 (nearest)	N/A	N/A
Sale Date	June 12, 2017	March 25, 2014	June 31, 2013
Sale Price	$214,000	$184,000	$193,000
Sale Price/Sq. Ft. (A.G.)	$124.35	$106.91	$91.90
Year Built	2006	2006	2006
Building Size	1,721 sq. ft.	1,721 sq. ft.	2,100 sq. ft.
Lot Size	1.04 acres	1.35 acres	0.21 acres
Style	1-story, frame (vinyl) 4 bdrms., 2 ba.	1-story, frame (vinyl) 3 bdrms., 2 ba.	2-story, frame (vinyl/brick) 4 bdrms.; 2.1 ba.
Basement	Full; partially finished	Full; unfinished	Full; finished
Utilities	Geothermal heat & cooling Well & septic	Geothermal heat & cooling Well & septic	Central Air; Forced-air heat Public Sewer
Other	2.5-car attached garage; Front porch and deck	2.5-car attached garage; Front porch	3-car attached garage Patio

8873 North Glasgow Road

1511 Hunters View Drive

The house at 8873 North Glasgow Road, is located approximately 8 miles northwest of Decatur, in a rural area. According to the Macon County Assessor's records, this house previously sold in March 2014 for $184,000. This indicates an increase in value of approximately 16 percent during a period where residential sale prices generally were not increasing. There is no lease for a wind turbine on this property. According to the most recent selling broker there was an issue with the well test; the yard was dug up to find the well and treat the problem. The yard is now back to normal condition. The broker also says that the house is in excellent condition and showed very well. The sellers added a wrap-around deck and finished part of the basement to add a fourth bedroom. The seller was being relocated and was offered a low price for the relocation fee, so the sellers put it on the market themselves and were able to sell it almost immediately for greater than the asking price. The broker stated that the turbine being installed proximate to the property is a possible reason for the quick sale at a higher price, so having a turbine close to this property potentially had a positive effect on the sale.

The house at 1511 Hunters View Drive, Mount Zion, has a similar, rural location, yet is settled in a suburban setting, and is approximately 4 miles south of Decatur. Although this house sits on a smaller lot than the Glasgow property, this is offset by the extra bedroom and the second floor. There is no lease for a wind turbine near this property.

ADJUSTMENT GRID

Sale No.	Location	Sale Date	Year Built	Building Size	Lot Size	Style	Basement	Utilities	Out-Buildings
1B	1511 Hunters View Drive Mount Zion, Illinois 62549	+	○	-	+	○	○	+	○

\+ Positive adjustment based on comparable being inferior in comparison to property #1A
\- Negative adjustment based on comparable being superior in comparison to property #1A
○ No adjustment necessary

The comparison will be made to the March 2014 date of sale because it is most similar in time to the sale date of the Mount Zion property.

Upward adjustments are made for the superior market conditions, larger lot size, and geothermal heating and cooling system of the Glasgow property. Downward adjustments are made for the superior building size of the Mount Zion property. When the adjustments noted above are made to the sale price of the Glasgow house, the two properties have essentially the same per square foot value. In other words, although the Mount Zion house is larger, the higher per foot sales price for the Glasgow house is justified by its superior condition and amenities, and its larger lot size. Thus, the difference in the sales price does not support the conclusion that there is any diminution in value resulting from the proximity of the Glasgow property to wind turbines. This is further supported by the subsequent sale of the Glasgow property, where the 2017 sale price increased by $17.44 per square foot over the 2014 sale price.

Logan County Matched Pair No. 1

Matched Pair #1 considers the recent sale of a property located at 2558 1254th Avenue, Emden, that is 2,200 feet from the nearest wind turbine located in the Rail Splitter Wind Farm, with approximately four additional turbines visible from the property to the northwest. Rail Splitter Wind Farm was constructed in 2008-2009 and came on line in July 2009.

LOGAN COUNTY MATCHED PAIR NO. 1

	1A PROXIMATE TO A WIND TURBINE	1B NOT PROXIMATE TO A WIND TURBINE
Address	2558 1254th Ave. Emden, Illinois	801 1250th Ave. Lincoln, Illinois
Ft. from Turbine	2,200 (nearest)	N/A
Sale Date	March 19, 2015	January 15, 2015
Sale Price	$108,000	$97,900
Sale Price/Sq. Ft. (A.G.)	$62.21	$71.46
Year Built	1965	1970
Building Size	1,736 sq. ft.	1,370 sq. ft.
Lot Size	1.38 acres	1.33 acres.
Style	Ranch; frame (brick) 3 bdrms., 2 ba.	Ranch; frame (vinyl/stone) 3 bdrms., 2 ba.
Basement	N/A	Full; unfinished
Other	2-car 460 sq. ft. attached garage enclosed porch	2-car 672 sq. ft. attached garage

2558 1254th Avenue

801 1250th Avenue

The house at 2558 1254th Avenue, Emden[5], is located approximately 8 miles north of Lincoln, in a rural area. According to the Logan County Assessor's records, this house previously sold in November 2011 for $102,500. This indicates an increase in value of approximately 5 percent during a period when residential sale prices generally were not increasing. There is no lease for a wind turbine on this property.

The house at 801 1250th Avenue, Lincoln, has a similar, rural location, approximately 8 miles south of Lincoln. According to the Logan County Assessor's records, this house sold in June 2010 for $128,500, and then was sold in July 2014 in a Sheriff's sale. The January 2015 sale is considered arm's length by the Assessor. The Lincoln house is approximately 20 percent smaller in size than the Emden property, a significant upward adjustment is considered appropriate. A downward adjustment is made for the full basement of the Lincoln property compared to the lack of a basement of the Emden property. The lack of an enclosed porch is offset by the larger garage size.

ADJUSTMENT GRID

Sale No.	Location	Sale Date	Year Built	Building Size	Lot Size	Style	Basement	Utilities	Out-Buildings
1B	801 1250th Ave. Lincoln, Illinois	○	○	+	○	○	-	○	○

\+ Positive adjustment based on comparable being inferior in comparison to property #1A
\- Negative adjustment based on comparable being superior in comparison to property #1A
○ No adjustment necessary

5 This address is taken from the Logan County records; some maps indicate that this property is located at 2558 1250th Avenue, in either unincorporated Emden or Atlanta.

There is a $9.25 per square foot difference in sale price between the Emden house and the Lincoln house, in favor of the Emden house. However, when the adjustments noted above are taken into consideration, the difference in the per square foot sale price of the two properties is fully justified. Thus, the difference in the sales price does not support the conclusion that there is any diminution in value resulting from the proximity of the Emden property to wind turbines.

Matched Pair Analysis Conclusions

Based on these matched pairs and sales/resales of properties proximate to wind turbines, there does not appear to have been any measurable negative impact on surrounding property values due to the proximity of a wind farm.

Agricultural Land Values

Agricultural land values are typically tied to the productivity of the land and to the commodity prices of crops like corn and soy beans. Other factors include favorable interest rates, and the supply of land compared to the number of buyers. The most recent "Ag Letter" for the 9th District, which includes South Dakota, and is published by the Federal Reserve of Minneapolis, indicated a modest 3 percent increase in agricultural land values after 3 years of mild downward year-over-year changes.

The South Dakota Agricultural Land Trends produced by South Dakota State University[6] reported agricultural land values in Deuel County averaged $4,613 per acre in 2016, and $5,066 per acre in 2015. A more recent survey covering the period between February 2016, and February 2017 supported the Fed's report of an increase in average land value with an average land value of $4,654 per acre.[7] The most likely buyer of agricultural land in South Dakota is an existing farmer, with neighboring farmers paying higher prices than investors. The prognosis appears to be for stable, if not slightly rising land values. The following table and map illustrates values as of February 1, 2017, by region, including Codington and Grant counties in the Northeast region.

6 https://igrow.org/up/resources/07-3007-2017.pdf, 2017 SDSU South Dakota Farm Real Estate Survey

7 https://igrow.org/up/resources/07-3007-2017.pdf, 2017 SDSU South Dakota Farm Real Estate Survey

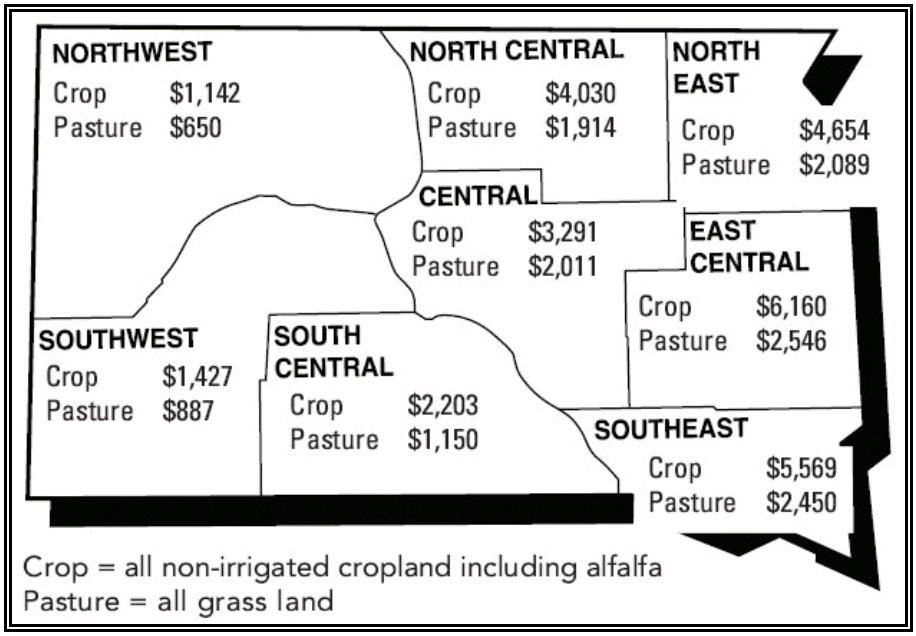


Table 3. Average reported value and annual percentage change in value of South Dakota agricultural land by type of land by region, February 2013-2017.

Type of Land	Southeast	East Central	Northeast	North Central	Central	South Central	Southwest	Northwest	STATE
	dollars per acre								
Nonirrigated Cropland									
Average value, 2017*	$5,569	$6,160	$4,654	$4,030	$3,291	$2,203	$1,427	$1,142	$3,903
Average value, 2016	$5,653	$6,116	$4,613	$4,177	$3,843	$2,168	$1,264	$1,187	$4,094
Average value, 2015	$5,887	$6,329	$5,066	$4,275	$3,895	$2,283	$1,347	$1,193	$4,265
Average value, 2014	$6,331	$7,114	$5,291	$4,614	$3,953	$2,087	$820	$870	$4,478
Average value, 2013	$5,903	$6,828	$4,843	$4,562	$3,580	$1,994	$900	$792	$4,249
Annual % change 17/16	-1.5%	0.7%	0.9%	-3.5%	-14.4%	1.6%	12.9%	-3.8%	-4.7%
Pasture/ Rangeland**									
Average value, 2017**	$2,450	$2,546	$2,089	$1,914	$2,011	$1,150	$887	$650	$1,215
Average value, 2016	$2,566	$2,781	$2,028	$1,957	$2,219	$1,330	$715	$760	$1,222
Average value, 2015	$2,719	$2,727	$2,136	$1,758	$2,100	$1,338	$851	$630	$1,187
Average value, 2014	$2,698	$2,861	$1,859	$1,600	$1,828	$1,187	$571	$436	$987
Average value, 2013	$2,308	$2,765	$1,759	$1,473	$1,636	$994	$529	$444	$909
Annual % change 17/16	-4.5%	-8.5%	3.0%	-2.2%	-9.4%	-13.5%	24.1%	-14.5%	-0.6%

Source: 2017 and earlier South Dakota Farm Real Estate Market Surveys
*cropland now includes all alfalfa acres
** 2017 pasture land variable has been redefined and includes all grass acres
Statewide average land values are based on 2002 land use weights

The following table summarizes recent agricultural land sales larger than 10 acres in Codington County in or near the footprint of the proposed wind farm. There were no recent agricultural land sales in Grant County.

LAND SALES SUMMARY

SALE NO.	LOCATION	SALE PRICE	SALE DATE	LAND AREA (ACRES)	NCCPIS*	SALE PRICE PER ACRE
1	15496 County Road 9 1/10 South Shore, South Dakota	$50,000	4/15	99.00	0.41	$505.05
2	15629 457th Ave. South Shore, South Dakota	$53,500	1/14	118.90	0.34	$449.96
3	15511 460th Ave. South Shore, South Dakota	$60,000	12/15	37.90	0.46	$1,583.11
4	45323 157th St. South Shore, South Dakota	$140,000	10/16	63.40	0.36	$2,208.20
5	46156 155th St. South Shore, South Dakota	$272,079	12/15	315.10	0.30	$863.47

*National Commodity Crop Productivity Index - based on AcreValue.com GIS informational map. The NCCPI uses a scale of 0 to 1, with 0 having a lower productivity potential and 1 a higher potential. This scale was developed using soil chemical and physical properties, water availability, climate, and landscape values. The NCCPI has indexes for corn, wheat and cotton (USDA, 2008)

Agricultural Land Sales and Wind Farms

The above land sales reveal that the agricultural land in the area of the project footprint is far below average for the northeast region of South Dakota, and adding wind turbines and land leases should only benefit the land prices and productivity. I was unable to discover any sales of South Dakota farmland in which the transaction included a wind turbine, and upon closer inspection, the existing wind farms are located in extremely remote areas of the state with few or no residential houses within 3 miles. However, there were a few sales in the neighboring state of Minnesota in Freeborn County, which is home to the Bent Tree Wind Farm and provides similar demographics to the project area of Dakota Range. The following table summarizes the three sales in 2015 and 2016 of farmland with turbine leases. Although this survey is not exhaustive, it appears that the turbines may have had a positive impact on the sale price.

AGRICULTURAL LAND VALUES WITH TURBINES - FREEBORN COUNTY

	2015			2016		
	No. Of Sales	Range in Sale Price/Ac.	Average Sale Price/Ac.	No. Of Sales	Range in Sale Price/Ac.	Average Sale Price/Ac.
Bent Tree Wind Farm	2	$7,011 to $9,502	$8,257	1	$7,011	$7,011
County Average			$6,547			$6,416

Wind turbines typically are considered to be of significant benefit to farmers; Iowa farmers interviewed by the *Omaha World Herald*, were positive about the stable income as opposed to the vicissitudes of commodity prices.[8] Franklin County reported lowering real estate taxes for the county as a whole because of the taxes generated by the wind turbines in that county. Support for good prices comes from the lack of land for sale, stable commodity prices, and low interest rates. Marginal land in areas where wind turbines are located or proposed is popular with investors.[9]

Although there has been no study of the impact of wind turbines on agricultural land sales for South Dakota that I could discover, a report in Illinois, the *2016 Illinois Land Values and Lease Trends*, indicated that the impact of wind turbine leases is being felt in McLean, Livingston, and Woodford counties, where turbine leases have provided "income diversification, beyond agriculture, which makes these tracts more attracting to an outside investor."[10] Further, they noted that "investors are still paying a little more of a premium for the wind turbines just as they had in the past few years."[11] The report notes that the premium is related directly to the number of years left on the lease.

Overall, it appears that there is little or no relationship between agricultural land values and the location of wind farms, with productivity being the driving force behind land values. However, wind farm lease revenue does appear to add to the marketability and value.

Local Real Estate Professionals

Local real estate professionals were contacted to discuss market conditions, specific market transactions, and to investigate whether they had experience with, or knowledge of any impact of wind farms on residential property values. Jim Aesoph of Aesoph Real Estate, Inc. is a broker with 27 years of experience in northeast South Dakota. MaRous and Company contacted Mr. Aesoph due to his highly regarded reputation in the area of the Dakota Range Wind Project. He stated that he contacted the assessors of Codington, Grant, and Roberts counties to discuss land prices in their respective county, and each of them informed Jim that although they have heard that the project is in production, they are not

8 http://www.omaha.com/money/turning-to-turbines-as-commodity-prices-remain-low-wind-energy/article_2814e2cf-83a3-547d-a09e-f039e935f399.html Accessed September 18, 2107.

9 http://www.agriculture.com/farm-management/farm-land/farmland-sales-hard-to-find-as-growers-hold-tight-keeping-land-value Accessed September 18, 2017.

10 Klein, David E., and Schnitkey, Gary, *2016 Illinois Land Values and Lease Trends*, Illinois Society of Professional Farm Managers and Rural Appraisers, Page 38.

11 Ibid. Page 42.

aware of any effect on land prices. He also stated that five years ago land prices were roughly $6,000 per acre, and now the average acre is approximately $4,000. The reduction in land prices, he mentions, is not due to the wind project, but due to the production of corn on the land.

Rick Mummert of Ron Holton Real Estate reported that residential conditions in both Freeborn and Mower counties in Minnesota had been stable through the last 3 years, primarily due to the very rural nature of the area however the area is benefitting from the low interest rates. He reported that the Highway 14 corridor had experienced increases in residential values; in his opinion, the difference was due to the more developed nature of the area and the availability of jobs.

Interviews with brokers proximate to wind farms in Illinois yielded similar results. Although a number of them wished to remain anonymous, they stated that they did not believe that the proximity to wind turbines had any bearing on the sale prices of residential properties in the area.

Michael Crowley, Sr., SRA of Real Estate Consultants, Ltd., Spring Valley, Illinois, has had extensive experience with wind farm development in Central Illinois, including projects in Bureau, Whiteside, and Lee counties. Mr. Crowley has been unable to document any loss in property values attributable to the proximity of wind turbines.

South Dakota Assessors Survey - November 2017

In November 2017 my office conducted a survey of the supervisor of assessments or a deputy supervisor in six counties in South Dakota in which wind farms with more than 25 turbines currently are operational, and South Dakota has more than seven wind farms with 400 wind turbines. As of 2016, the AWEA reported there were approximately 14 wind projects with approximately 583 wind turbines in the state with additional farms being added each year. The interviews were intended to allow the assessment officials to share their experience regarding the wind farm(s) impact upon the market values and/or assessed values of surrounding properties. The detailed analysis is attached in the addenda at the end of this report. The following is a summary of the results of that survey:

- Without exception, the interviewees reported that there was no market evidence to support a negative impact upon residential property values as a result of the development of and the proximity to a wind farm facility. In some counties, this results from the very rural nature of the area in which the projects are located;
- In the past 5 years, the assessor's offices have not experienced a real estate tax appeal based upon wind farm-related concerns. There have been no reductions in assessed valuations related to wind turbines.
- As the available market data do not support the claim of a negative impact upon residential or agricultural values, residential and agricultural assessed values have fluctuated consistently within counties as influenced by market conditions, with no regard for proximity to a wind farm.
- Virtually all assessors volunteered that the wind farms provided positive economic benefits to their counties and, in fact, had a positive impact on real estate values.

Iowa Assessors Survey - August/September 2017

In August and September 2017 my office conducted a survey of the supervisor of assessments or a staff member in 26 counties in Iowa in which wind farms with more than 25 turbines currently are operational, and Iowa has more than 38 wind farms with 3,706 wind turbines. As of 2016, the AWEA reported there were approximately 107 wind projects with approximately 4,143 wind turbines in the state with additional farms being added each year. The interviews were intended to allow the assessment officials to share their experience regarding the wind farm(s) impact upon the market values and/or assessed values of surrounding properties. The following is a summary of the results of that survey:

- Without exception, the interviewees reported that there was no market evidence to support a negative impact upon residential property values as a result of the development of and the proximity to a wind farm facility. In some counties, this results from the very rural nature of the area in which the projects are located;

- In the past 18 months, the assessor's offices have not experienced a real estate tax appeal based upon wind farm-related concerns. There have been no reductions in assessed valuations related to wind turbines.
- As the available market data do not support the claim of a negative impact upon residential values, residential assessed values have fluctuated consistently within counties as influenced by market conditions, with no regard for proximity to a wind farm.
- Virtually all assessors volunteered that the wind farms provided positive economic benefits to their counties and, in fact, had a positive impact on real estate values.
- Agricultural properties are taxed based upon a productivity formula that is not impacted by market data and external influences.

Minnesota Assessors Survey - January 2017

In late January 2017, my office conducted a survey of the Assessors or a staff member in eight Minnesota counties where large numbers of wind turbines currently are operational. There are several counties with small numbers of wind turbines that were not included in the survey. As of 2015, the AWEA reported there were approximately 97 wind projects with approximately 2,400 wind turbines in the state with additional farms being added each year. The interviews were intended to allow the assessment officials to share their experience regarding the wind farm(s) impact upon the market values and/or assessed values of surrounding properties. The following is a summary of the results of that survey:

- With one exception, the interviewees reported that there was no market evidence to support a finding that there has been a negative impact upon residential property values as a result of the development of and the proximity to a wind farm facility. In some counties, the assessors believed this to be the result of the very rural nature of the area in which the projects are located.
- The exception, the Dodge County Assessor, reported receiving two complaints from residential property owners regarding the value impact of proximity to wind turbines; however, the Assessor was unable to find data to support the contentions.
- Without exception, where there was sufficient data to analyze, the County Assessors reported that both residential and agricultural assessed property values within the wind farm footprints have fluctuated consistently within counties as influenced by market conditions, with no regard for proximity to a wind farm.

Based on Bruce Nielson's, Lincoln County Assessor, report, a recent residential transaction in a township in which wind turbines are located sold $70,000 higher than the assessor's opinion of market value.

Illinois Assessors Survey - Updated October 6 - 19, 2016

In March 2015, and updated in October 2016, my office conducted a survey of the supervisor of assessments or a staff member in 18 counties in Illinois in which wind farms currently are operational. As of 2016, the AWEA reported there were approximately 48 wind projects with approximately 2,579 wind turbines in the state with additional farms being added each year. The interviews were intended to allow the assessment officials to share their experience regarding the wind farm(s) impact upon the market values and/or assessed values of surrounding properties. The following is a summary of the results of that survey:

- Without exception, the interviewees reported that there was no market evidence to support a negative impact upon residential property values as a result of the development of and the proximity to a wind farm facility. In some counties, this results from the very rural nature of the area in which the projects are located;
- In the past 18 months, the assessor's offices have not experienced a real estate tax appeal based upon wind farm-related concerns. As of the date of this report, there are more than 46 wind farms with 2,348 wind turbines and more than 1,000,000 properties in these counties. There have been no reductions in assessed valuations related to wind turbines.[12]
- As the available market data do not support the claim of a negative impact upon residential values, residential assessed values have fluctuated consistently within counties as influenced by market conditions, with no regard for proximity to a wind farm.
- Agricultural properties are taxed based upon a productivity formula that is not impacted by market data and external influences.

12 A law suit was apparently filed in 2013 against the Supervisor of Assessments in Vermilion County by a homeowner proximate to wind turbines; however, there has been no further action on the matter.

Literature Review

I am familiar with several academic and peer-reviewed studies of the impact of wind turbines on residential property values. There are no peer reviewed studies for the state of South Dakota, however the following studies are consistent with our findings in South Dakota.[13] These are summarized below:

Municipal Property Assessment Corporation (MPAC) Study, Ontario, Canada

This study originally was conducted in 2008 and was updated in 2012 and 2016. The conclusions in all three studies are similar: "there is *no statistically significant impact on sale prices* of residential properties in these market areas resulting from proximity to an IWT, when analyzing sale prices." (Emphasis in original. IWT is Industrial Wind Turbine. 2012 Page 5) Using 2,051 properties and generally accepted time adjustment techniques, MPAC "cannot conclude any loss in price due to the proximity of an IWT." (2012 Page 29) Further, Appendix G of the 2012 MPAC report states "Re-sale Analysis" states in the "Summary of Findings" "MPAC's own re-sale analysis using a generally accepted methodology for time adjustment factors indicates no loss in price based on proximity to the nearest IWT."

Lawrence Berkeley National Laboratory (LBNL) Studies, Nationwide, 2009, and 2013

The 2009 study included analysis of 7,489 sales within 10 miles of 11 wind farms and 125 post-construction sales within 1 mile of a wind turbine. The study used rural settings and wind farms of more than 50 turbines, and considered area stigma, scenic vista sigma, and nuisance stigma in varying distances from a wind turbine. The 2013 LBNL study included 51,276 sales located in nine states and proximate to 67 wind farms, and 376 post-construction sales within 1 mile of a wind turbine. Like the 2009 study, all were located in rural settings and near wind farms of more than 50 turbines. This study concentrated on nuisance stigma in varying distances from a wind turbine. The study found no statistically significant evidence that turbines affect sale prices. Neither study found statistical evidence that home values near turbines were affected.

University of Rhode Island, Rhode Island, 2013

Structured similarly to the LBNL studies, this study included 48,554 total sales proximate to 10 wind farms, and 412 post-construction sales within 1 mile of a turbine. These wind farms were mostly small facilities in urban settings. The study included nuisance and scenic vista stigmas. Page 421 of the report stated, "Both the whole sample analysis and the repeat sales analysis indicate that houses within a half mile had essentially no price change ..." after the turbines were erected.

13 Although I have read these studies, the substance of these summaries was taken from a seminar conducted by the Appraisal Institute on March 5, 2015.

University of Guelph, Melancthon Township, Ontario, Canada, 2013

This study analyzed two wind farms in the township, using 5,414 total sales and 18 post-construction sales within 1 kilometer of a wind turbine. The study included nuisance and scenic vista stigmas. Page 365 of the study stated that "(T)hese results do not corroborate the concerns regarding potential negative impacts of turbines on property values."

University of Connecticut/LBNL, Massachusetts, 2014

This study included 312,677 total sales proximate to 26 wind farms, and 1,503 post-construction sales within 1 mile of a wind turbine. These wind farms were located in urban settings and primarily were proximate to small wind farms. The study included wind turbines and other environmental amenities/disamenities (including beaches and open spaces/landfills, prisons, highways, major road, and transmission lines) together, for nuisance stigma. "Although the study found the effects from a variety of negative features ... and positive features ... the study found no net effects due to the arrival of turbines."

These studies had a combined number of 2,500 transactions within 1 mile of operating turbines and found no evidence of value impact.

Conclusions

As a result of the market impact analysis undertaken, I concluded that there is no market data indicating the Project will have a negative impact on either rural residential or agricultural property values in the surrounding area. Further, market data from South Dakota, as well as other states, supports the conclusion that the Project will *not* have a negative impact on rural residential or agricultural property values in the surrounding area. Finally, for agricultural properties that host turbines, the additional income from the wind lease may increase the value and marketability of those properties. These conclusions are based on the following:

- The proposed use will meet or exceed all the required development and operating standards;
- Controls, such as setbacks and noise limits, are in place to insure on-going compliance;
- There are significant financial benefits to the local economy and to the local taxing bodies from the development of the proposed wind farm;
- The proposed wind farm will create well-paid jobs in the area which will benefit overall market demand;
- An analysis of residential sales proximate to wind farms did not support any finding that proximity to a wind turbine had a negative impact on property values;
- An analysis of agricultural land values in Iowa did not support any finding that agricultural land values are negatively impacted by the proximity to wind turbines;
- Reports from Minnesota, Iowa, and Illinois indicate that wind turbine leases add value to agricultural land; and
- A survey of County Assessors in 6 South Dakota counties, 26 Iowa counties, 8 Minnesota counties, and 18 Illinois counties in which wind farms with more than 25 turbines are located determined that there was no market evidence to support a negative impact upon residential property values as a result of the development of and the proximity to a wind farm, and that there were no reductions in assessed valuation.

This report is based on market conditions existing as of January 29, 2018. This market impact study has been prepared specifically for the use of the client and to potentially support an application to allow the development of the Dakota Range Wind Project, in Codington County and Grant County, South Dakota. Any other use or user of this report is considered to be unintended.

Respectfully submitted,
MaRous & Company

Michael S. MaRous, MAI, CRE
South Dakota Certified General #1639-T-2018 (8/27/18 expiration)
Illinois Certified General - #553.000141 (9/19 expiration)

CERTIFICATE OF REPORT

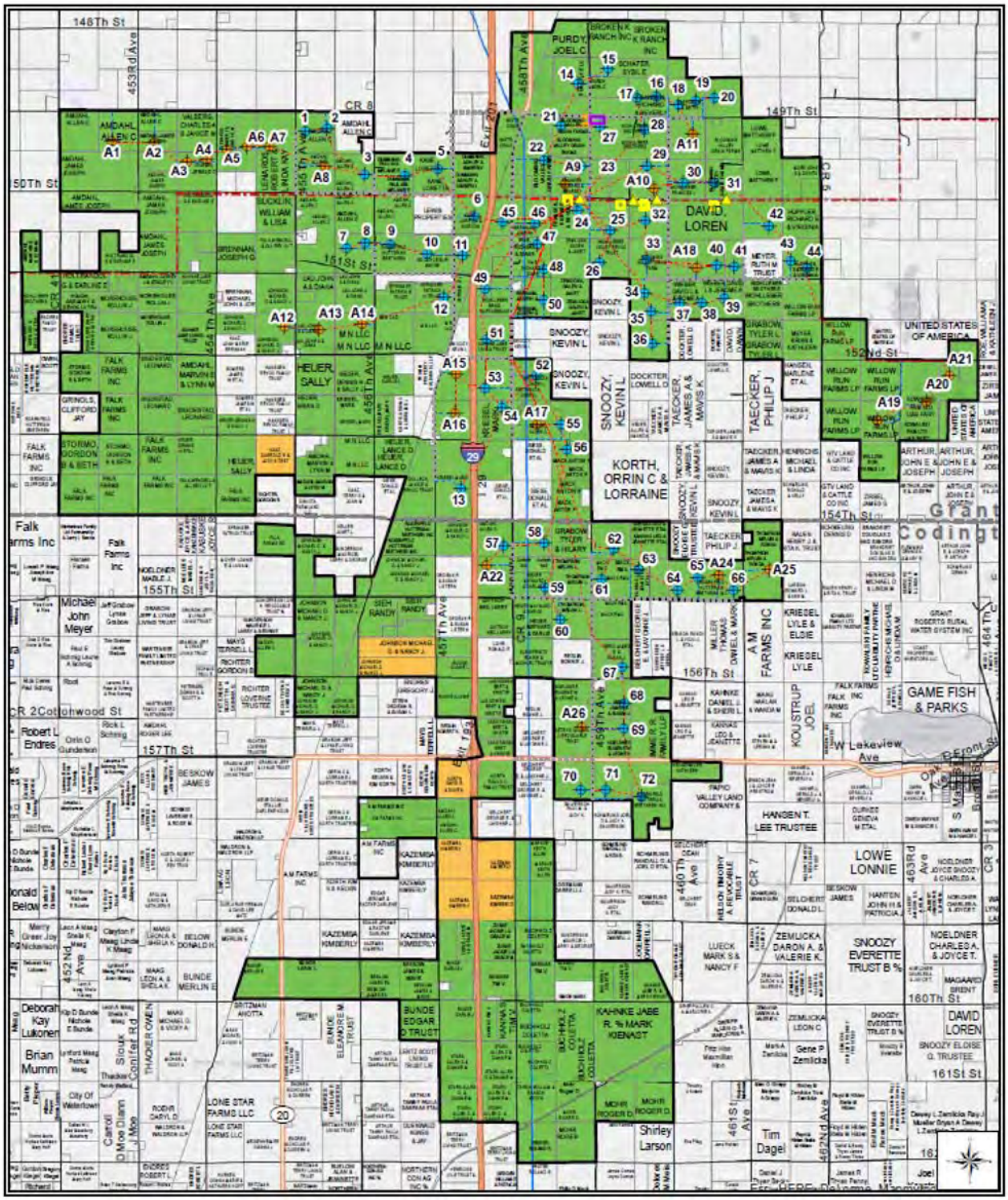
I do hereby certify that:

1. The statements of fact contained in this report are true and correct;
2. The reported analyses, opinions, and conclusions are limited only by the reported assumptions and limiting conditions, and are my personal, impartial, and unbiased professional analyses, opinions, conclusions, and recommendations:
3. I have no present or prospective personal interest in the property that is the subject of this report and no personal interest with respect to the parties involved;
4. I have performed no services, as an appraiser or in any other capacity, regarding the property that is the subject of this report within the three-year period immediately preceding acceptance of this assignment;
5. I have no bias with respect to the property that is the subject of the work under review or to the parties involved with this assignment;
6. My engagement in this assignment was not contingent upon developing or reporting predetermined results;
7. My compensation for completing this assignment is not contingent upon the development or reporting of predetermined value or direction in value that favors the cause of the client, the amount of the value opinion, the attainment of a stipulated result, or the occurrence of a subsequent event directly related to the intended use of this appraisal consulting assignment;
9. My analyses, opinions, and conclusions were developed, and this report has been prepared in conformity with the *Uniform Standards of Professional Appraisal Practice;*
10. I have made a personal inspection of the subject of the work under review;
11. Joseph M. MaRous provided significant appraisal review assistance to the person signing this certification;
12. The reported analysis, opinions, and conclusions were developed, and this report has been prepared, in conformity with the Code of Professional Ethics and Standards of Professional Appraisal Practice of the Appraisal Foundation;
12. The use of the report is subject to the requirements of the Appraisal Institute relating to review by its duly authorized representatives; and
13. As of the date of this report, Michael S. MaRous, MAI, CRE, has completed the continuing education requirements for Designated Members of the Appraisal Institute.

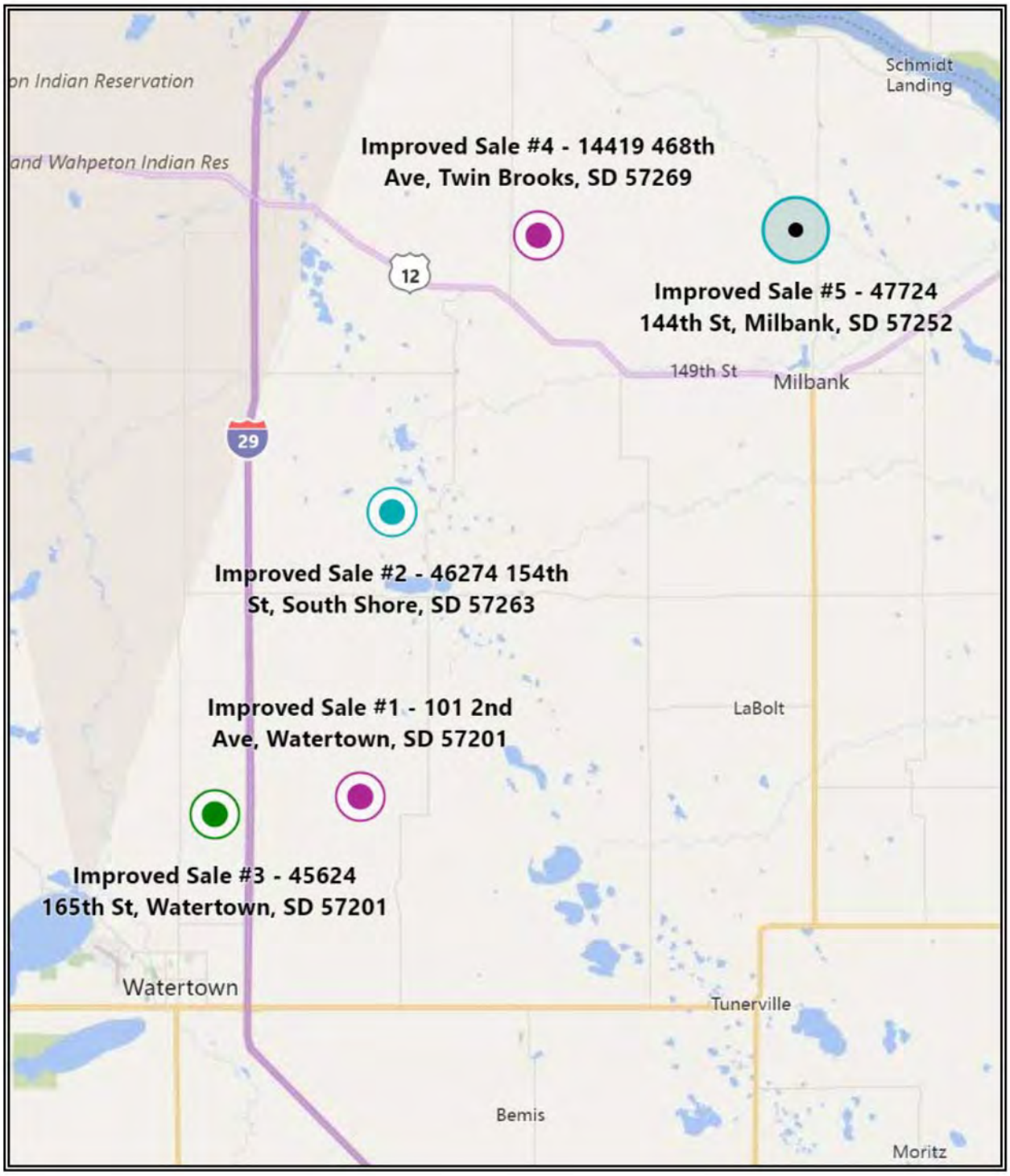
Respectfully submitted,
MaRous & Company

Michael S. MaRous, MAI, CRE
South Dakota Certified General #1639-T-2018 (8/27/18 expiration)
Illinois Certified General - #553.000141 (9/19 expiration)

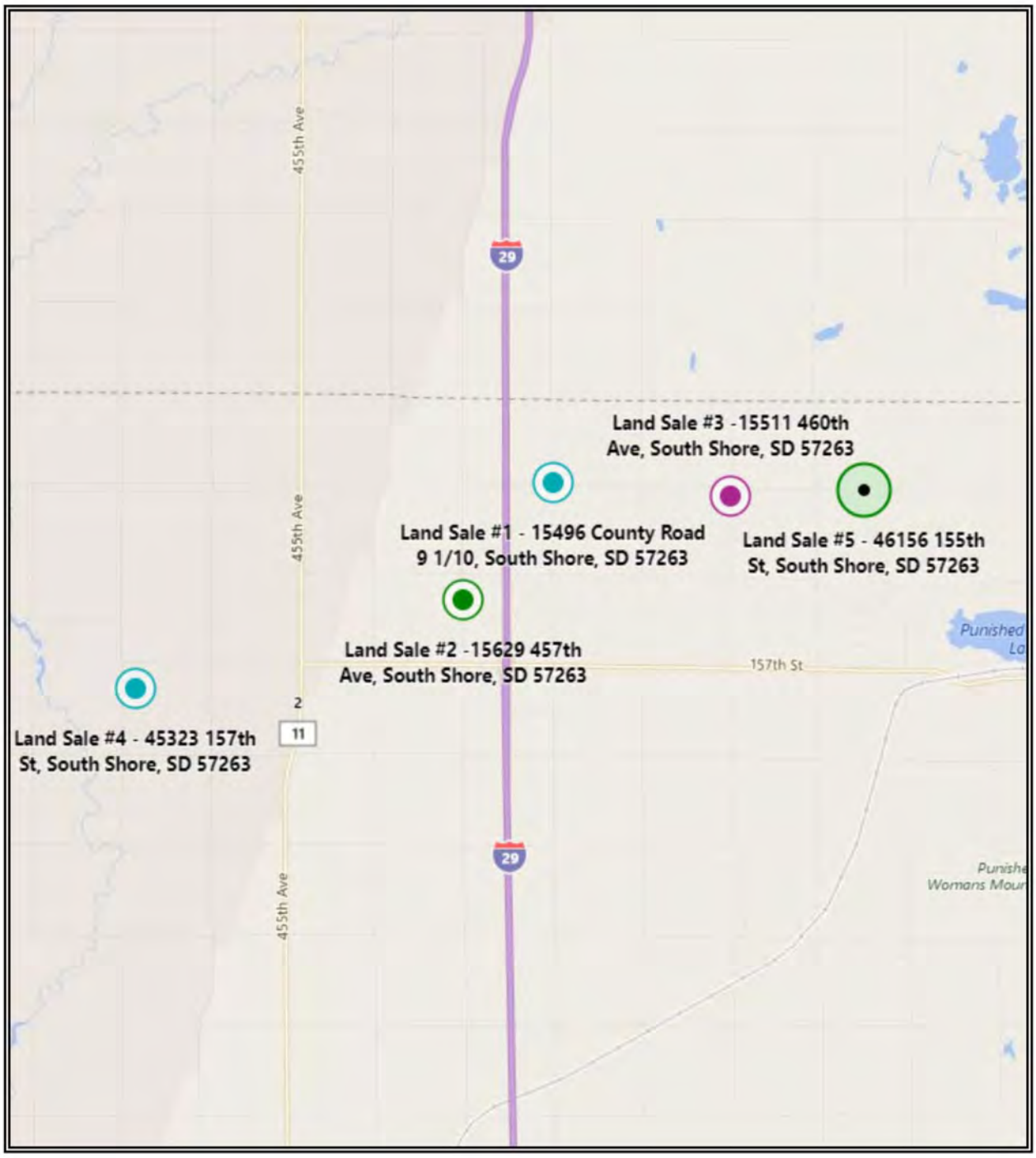
ADDENDA



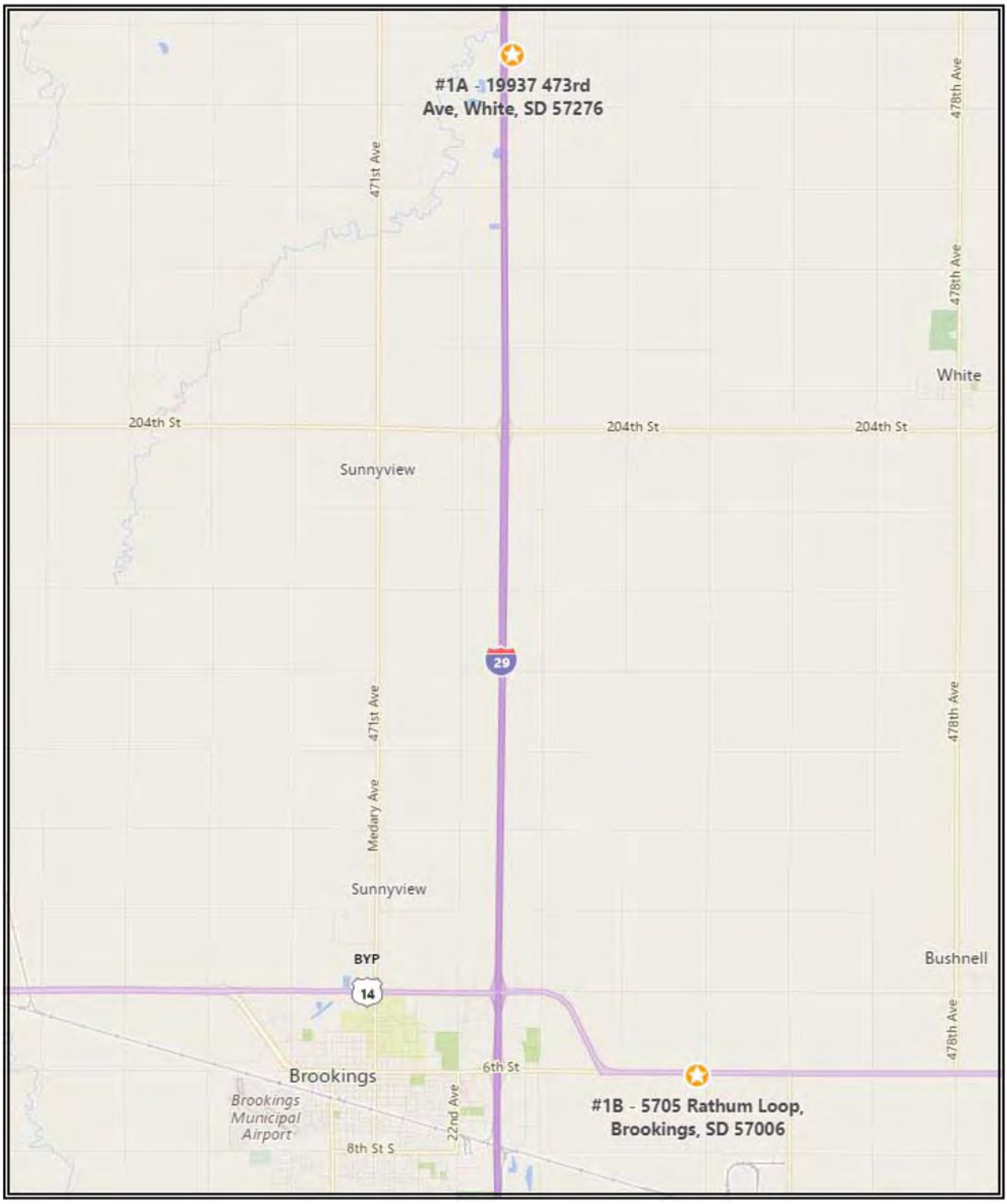
DAKOTA RANGE WIND PROJECT FOOTPRINT



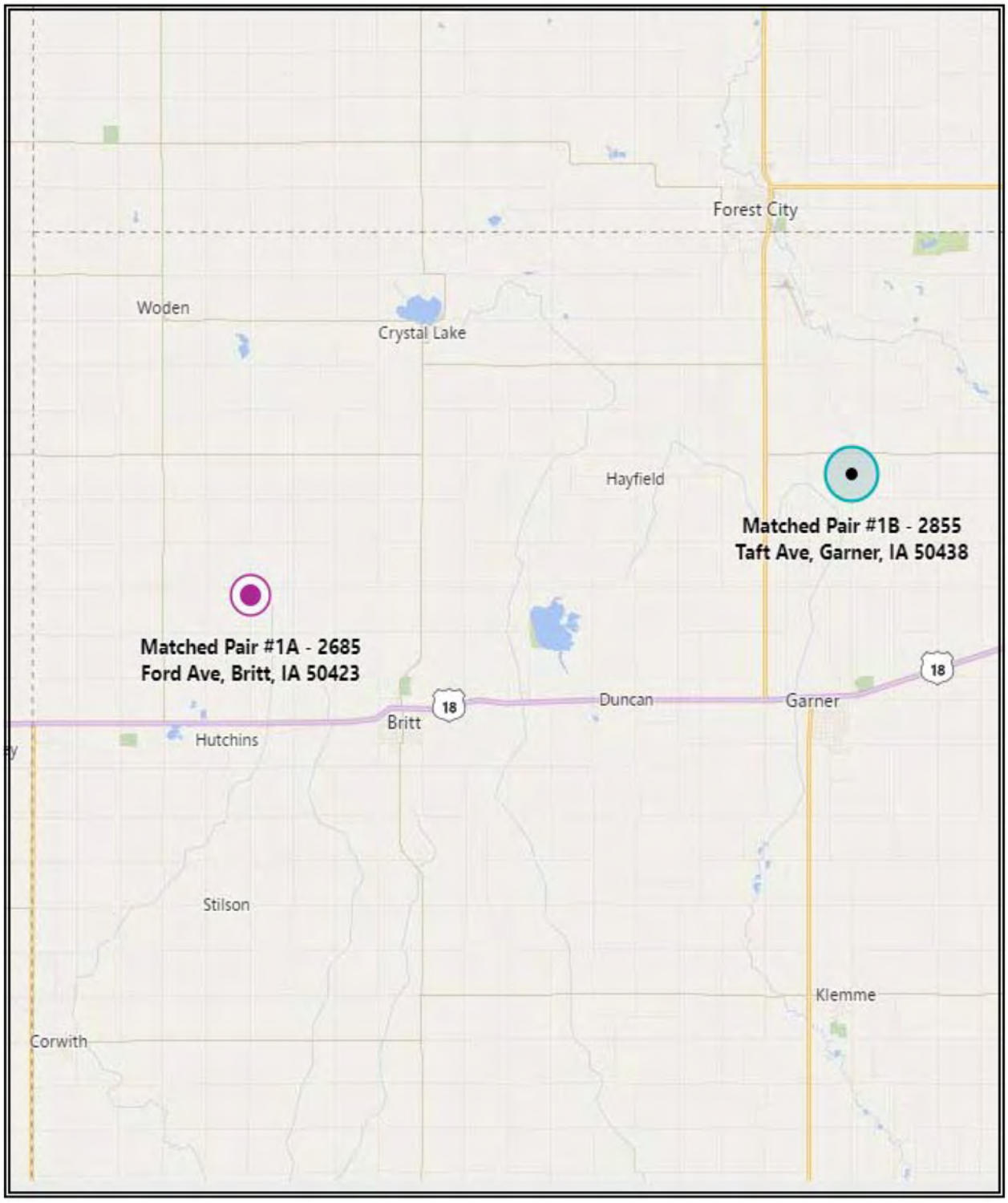
RECENT SINGLE-FAMILY HOUSE SALES LOCATION MAP



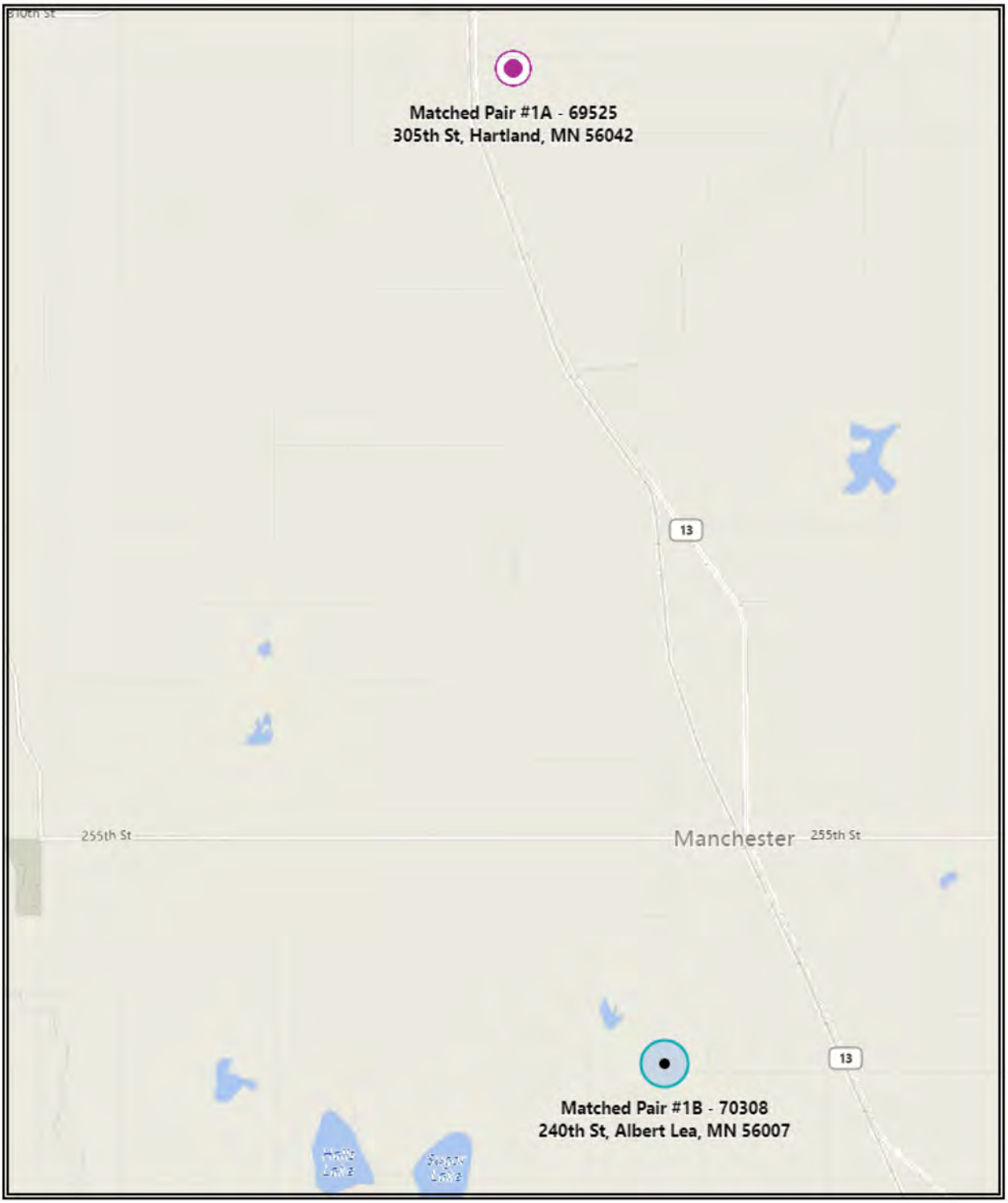
LAND SALES LOCATION MAP



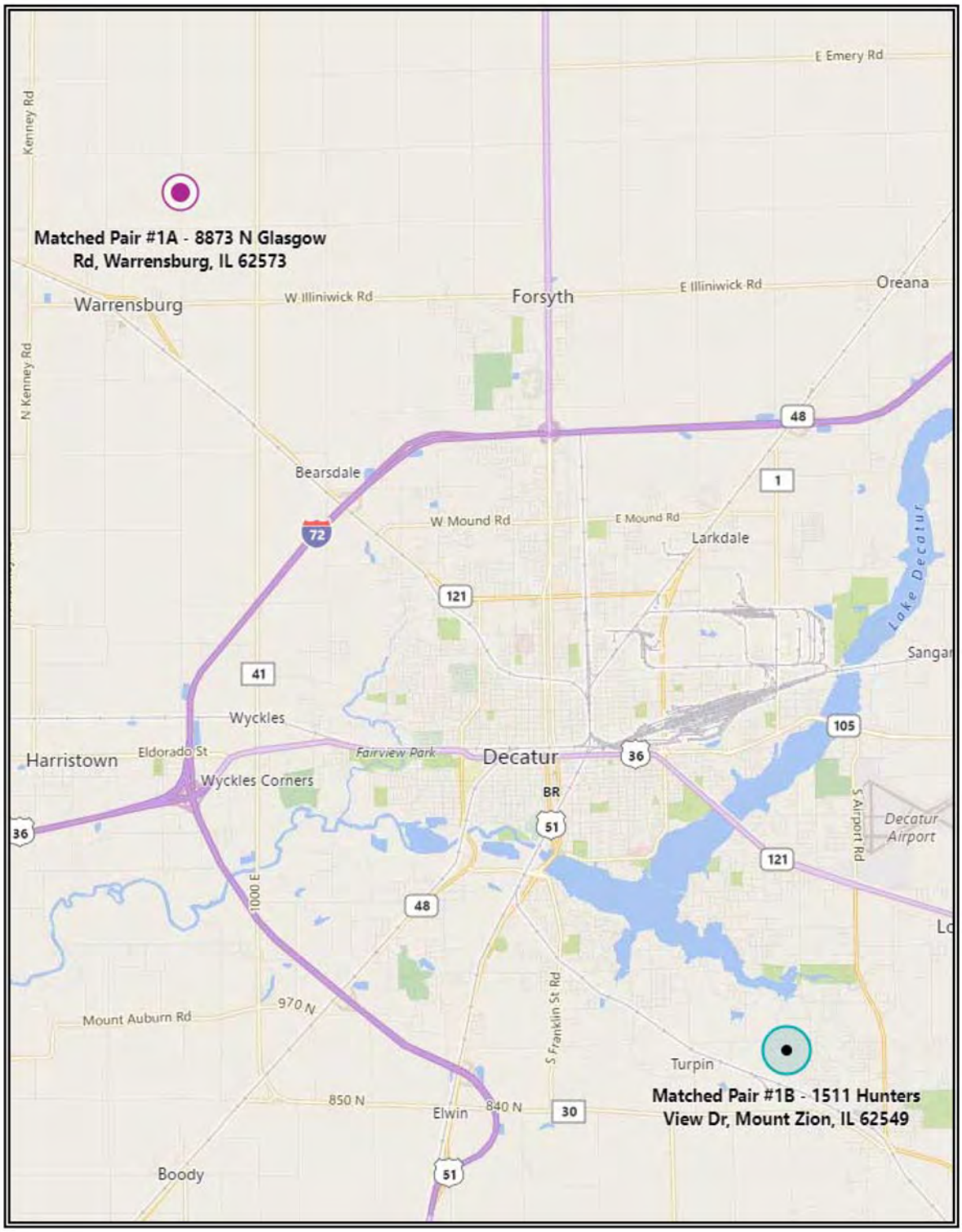
BROOKINGS COUNTY, SOUTH DAKOTA RESIDENCE LOCATION MAP



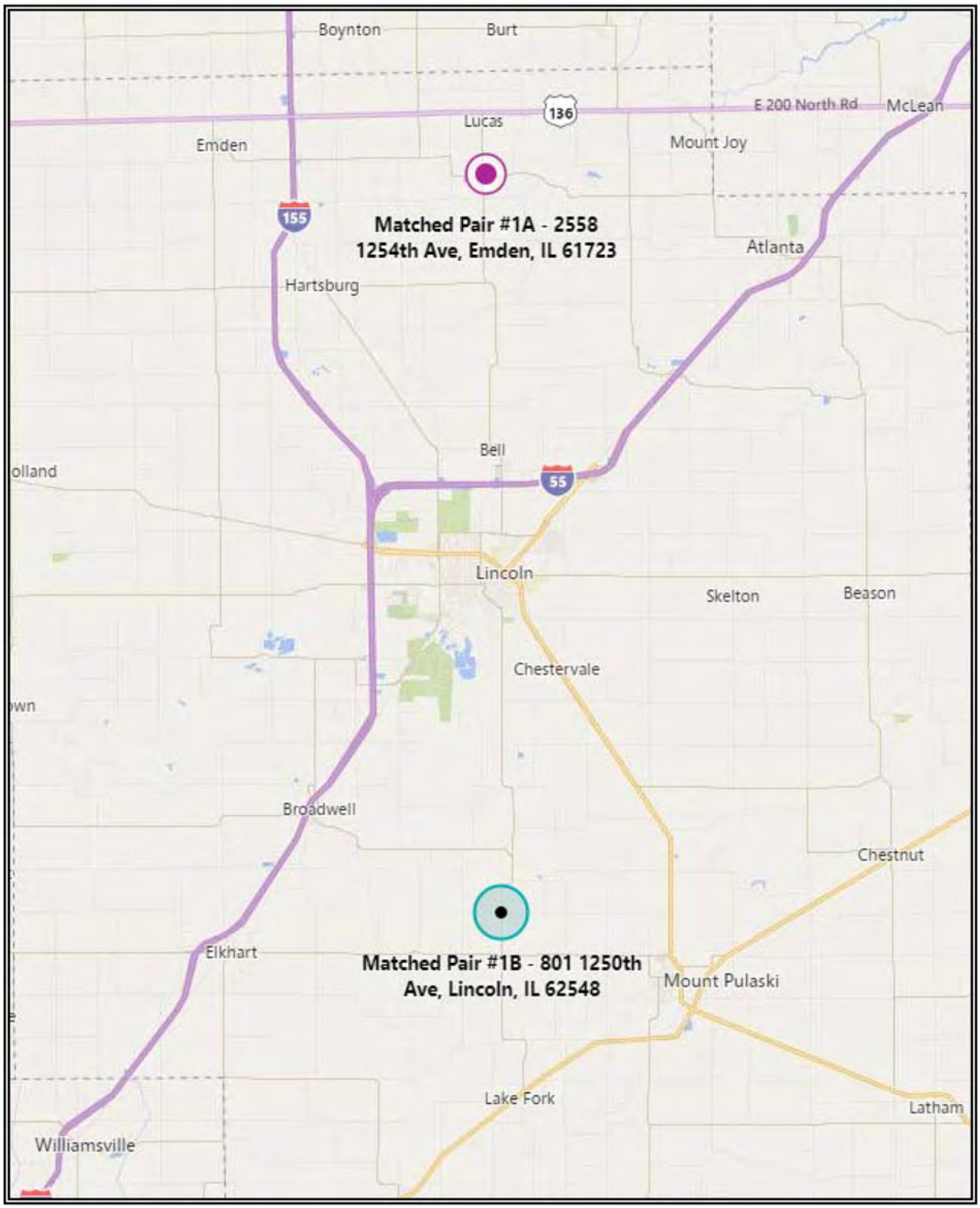
HANCOCK COUNTY, IOWA MATCHED PAIR LOCATION MAP



FREEBORN COUNTY, MINNESOTA MATCHED PAIR LOCATION MAP



MACON COUNTY, ILLIONOIS MATCHED PAIR LOCATION MAP



LOGAN COUNTY, ILLINOIS MATCHED PAIR LOCATION MAP

IMPROVED SALE PHOTOGRAPHS

101 2nd Avenue, Waverly

46274 154th Street, South Shore

45264 165th Street, Watertown

14419 468th Avenue, Twin Brooks

47724 144th Street, Milbank

South Dakota County Assessor Survey

South Dakota County Assessor Survey Analysis

A survey of assessors in 6 counties in South Dakota which wind farms currently are operational has been undertaken. The supervisors or deputy supervisors of assessments were interviewed. The interviews were intended to allow the assessment officials to share their experiences regarding the impact of the wind farm(s) upon the market values and/or the assessed values of surrounding properties. The interviews were conversational, but thoroughly discussed residential and agricultural values and impacts. The interviews were conducted on November 7, 2017.

Conclusions of the Study

Based on these interviews:

- Without exception, the interviewees reported that there was no market evidence to support a negative impact upon residential property values as a result of the development of, and the proximity to, a wind farm facility. In some counties, this results from the very rural nature of the area in which the projects are located.
- There have been no tax appeals in any county based upon wind farm-related concerns.
- In the past 18 months, the assessor's offices have not experienced a real estate tax appeal based upon wind farm-related concerns. As of the date of this report, there are more than 7 wind farms with 400 wind turbines within these counties. There have been no reductions in assessed valuations related to wind turbines.
- Residential assessed values have fluctuated consistently countywide as influenced by market conditions, with no regard for proximity to a wind farm.
- Agricultural properties are taxed based upon a productivity formula that is not impacted by market data and by external influences.

Scope of Project

The supervisors or deputy supervisors of assessments were interviewed. Each of the interviewees was familiar with the wind farm(s) located within their respective county. The following is the list of County Supervisors of Assessments contacted:

1. Aurora County	Ms. Leah Vissia	605-942-7164
2. Brookings County	Mr. Jacob Brehmer (Deputy)	605-696-8220
3. Charles Mix County	Ms. Denise Weber	605-487-7382
4. Day County	Ms. Dari Schlotte	605-345-9502
5. Hyde County	Ms. Carrie Stevenson	605-852-2070
6. Jerauld County	Ms. Janice Bender	605-539-9701

A map indicating the number of wind farms in each of these counties is included in this memorandum. A second map illustrates the number of the wind farms located in each of these counties.

Residential Market Values

Without exception, the interviewees reported that there was no market evidence to support a negative impact upon residential property values as a result of the development of, and the proximity to, a wind farm facility. Either as a request by a county board, in an attempt to appropriately assess newly constructed residences, or to support current assessed values, the supervisors of assessments have been particularly attentive to market activity in the area of the wind farms.

Aurora, Brookings, and Day Counties' Supervisors of Assessments all stated that a majority of the wind turbines were place with grazing and pasture land used for raising cattle. Each one of the assessors made it a point to note that they had personally witnessed the cows grazing right alongside turbines, indicating that the turbines had no effect, of any kind, on the animals.

Residential Assessed Values, Complaints/Tax Appeal Filings

The assessors reported that there have been no tax appeal filings based upon wind farm issues.

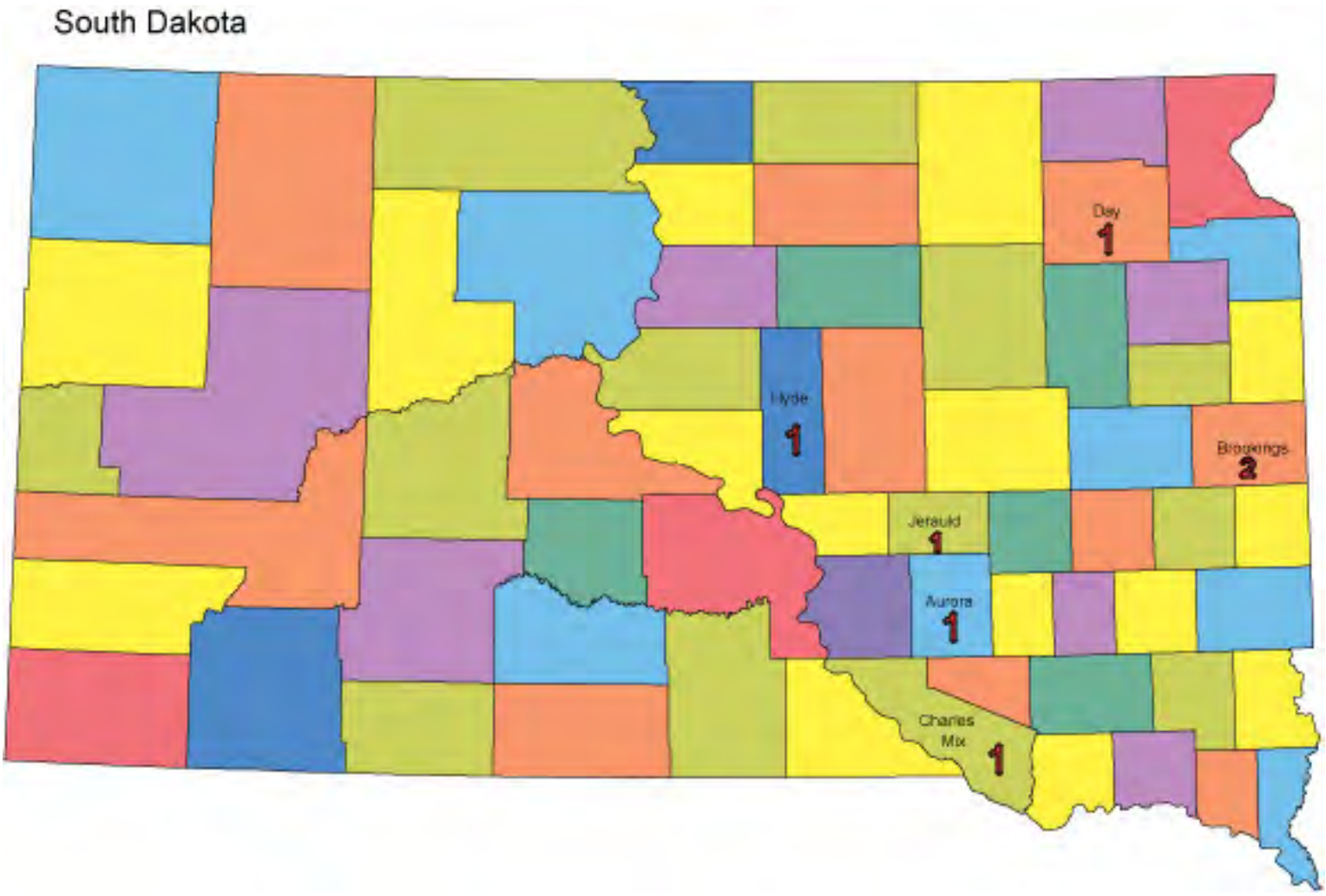
Ms. Carrie Stevenson, the Hyde County supervisor of assessments, did mention that the morning on the day the survey was taken Hyde County held its County Commissioners meeting. The topic of some of the meeting revolved around wind farms in the county. In attendance were approximately 30 residents, or a little over 2% of the total population of Hyde County. These residents showed up to voice their various complaints to the County Commissioners. The complaints were listened to and validated, yet in the end, there were no changes to property values given.

Consistently, the assessors reported that whatever initial concern there may have been regarding property values during the planning and approval stages of the various wind farms dissipated once the wind farm was constructed. Repeatedly, the assessors would state that the revenue that would come into the county and to each individual farmer would outweigh any initial concern that the residents would have about the wind farms joining their communities.

Agricultural Values/Assessed Values

The assessed values of agricultural properties are established based upon a productivity formula and are not driven by market data. Reportedly, assessed values of agricultural properties have been steady or increasing in recent years and are projected to continue increasing for the near future. The assessors reported that no major complaints have been received and/or no tax appeal filings have been filed for agricultural properties within the wind farm footprint.

Based on this survey, it does not appear that the Supervisors of Assessments in the 6 surveyed in South Dakota have reason to believe that the location of wind turbines in their county has had a negative impact on property values.



Map of South Dakota Counties Surveyed

Wind Farm Count by County

25 Turbines or Higher

Note: As depicted on this map, the locations of certain wind farms are approximations. In some instances, the wind farms are incorrectly shown to be located in adjacent counties. This map, as of the date of this survey, also shows the locations of smaller wind farms, but for the accuracy of this study we have only focused on the farms with 25 turbines or higher.

MICHAEL S. MAROUS
STATEMENT OF QUALIFICATIONS

Michael S. MaRous, MAI, CRE, is president and owner of MaRous and Company. He has appraised more than $15 billion worth of primarily investment-grade real estate in more than 25 states. In addition to providing documented appraisals, he has served as an expert witness in litigation proceedings for many law firms; financial institutions; corporations; builders and developers; architects; local, state, county, and federal governments and agencies; and school districts in the Chicago metropolitan area. His experience in partial interest, condemnation, damage impact, easement (including aerial and subsurface), marital dissolutions, bankruptcy proceedings, and other valuation issues is extensive. He has provided highest and best use, marketability, and feasibility studies for a variety of properties. Many of the largest redevelopment areas and public projects, including Interstate 355, the Chicago O'Hare International Airport expansion, the Chicago Midway International Airport expansion, and the McCormick Place expansion, are part of Mr. MaRous' experience. Mr. MaRous also has experience in regard to mediation and arbitration proceedings. Also, he has purchased and developed real estate for his own account.

APPRAISAL AND CONSULTATION EXPERIENCE

Industrial Properties

Business Parks	Manufacturing Facilities	Self-storage Facilities
Distribution Centers	Research Facilities	Warehouses

Commercial Properties

Auto Sales/Service Facilities	Gasoline Stations	Restaurants
Banquet Halls	Hotels and Motels	Shopping Centers
Big Box Stores	Office Buildings	Theaters

Special-Purpose Properties

Bowling Alleys	Nurseries	Tank Farms
Cemeteries	Riverboat Gambling Facilities	Underground Gas Aquifers
Farms	Schools	Utility Corridors
Golf Courses	Stadium Expansion Issues	Waste Transfer Facilities
Lumber Yards		Wind Farms

Residential Properties

Apartment Complexes	Condominium Developments	Subdivision Developments
Condominium Conversions	Single-family Residences	Townhouse Developments

Vacant Land

Agricultural	Easements	Rights of Way
Alleys	Industrial	Streets
Commercial	Residential	Vacations

Clients

Corporations	Law Firms	Private Parties
Financial Institutions	Not-for-profit Associations	Public Entities

EDUCATION

B.S., Urban Land Economics, University of Illinois, Urbana-Champaign
Continuing education seminars and programs through the Appraisal Institute
and the American Society of Real Estate Counselors, and real estate brokerage classes

PUBLIC SERVICE

Mayor, City of Park Ridge, Illinois (2003-2005)
Alderman, City of Park Ridge, including Liaison to the Zoning Board of Appeals and Planning and Zoning and
Chairman of the Finance and Public Safety Committees (1997-2005)

PROFESSIONAL AFFILIATIONS AND LICENSES

Appraisal Institute, MAI designation, Number 6159
Counselors of Real Estate, CRE designation
Illinois Certified General Real Estate Appraiser, License Number 553.000141 (9/19)
Indiana Certified General Real Estate Appraiser, License Number CG41600008 (6/18)
Wisconsin Certified General Real Estate Appraiser, License Number 1874-10 (12/19)
Minnesota Certified General Real Estate Appraiser, License Number 40330656 (8/18)
Pennsylvania Certified General Real Estate Appraiser, License Number GA004181 (6/19)
Iowa Certified General Real Estate Appraiser, License Number CG03468 (6/19)
South Dakota Certified General Real Estate Appraiser, Temporary License Number 1639-T-2018 (8/18)
Licensed Real Estate Broker (Illinois)

PROFESSIONAL ACTIVITIES

Mr. MaRous is past president of the Chicago Chapter of the Appraisal Institute. He is former chair and vice chair of the National Publications Committee and has sat on the board of *The Appraisal Journal*. In addition, he has served on and/or chaired more than 15 other committees of the Appraisal Institute, the Society of Real Estate Appraisers, and the American Institute of Real Estate Appraisers.

Mr. MaRous served as chair of the Midwest Chapter of the Counselors of Real Estate in 2006 and 2007 and has served on the National CRE Board since 2011. He sat on the Midwest Chapter Board of Directors, the Editorial Board of *Real Estate Issues,* and on various other committees.

Mr. MaRous also is past president of the Illinois Coalition of Appraisal Professionals. He also has been involved with many other professional associations, including the Real Estate Counseling Group of America, the Northwest Suburban Real Estate Board, the National Association of Real Estate Boards, and the Northern Illinois Commercial Association of Realtors.

PUBLICATIONS AND PROFESSIONAL RECOGNITION

Mr. MaRous has spoken at more than 20 programs and seminars related to real estate appraisal and valuation.

Author

"Low-income Housing in Our Backyards," *The Appraisal Journal*, January 1996
"The Appraisal Institute Moves Forward," *Illinois Real Estate Magazine*, December 1993
"Chicago Chapter, Appraisal Institute," *Northern Illinois Real Estate Magazine*, February 1993
"Independent Appraisals Can Help Protect Your Financial Base," *Illinois School Board Journal*, November-December 1990
"What Real Estate Appraisals Can Do For School Districts," *School Business Affairs*, October 1990

Awards

Appraisal Institute - George L. Schmutz Memorial Award, 2001
Chicago Chapter of the Appraisal Institute - Heritage Award, 2000
Chicago Chapter of the Appraisal Institute - Herman O. Walther, 1987 (Distinguished Chapter Member)

Reviewer or Citation in the Following Books

Rural Property Valuation, 2017
Real Estate Damages, 1999, 2008, and 2016
Golf Property Analysis and Valuation, 2016
Dictionary of Real Estate Appraisal, Fourth Edition, 2002 and Sixth Edition, 2015
Market Analysis for Real Estate, 2005 and 2014
Appraisal of Real Estate, Twelfth Edition, 2001, Thirteenth Edition, 2008, Fourteenth Edition, 2013
Shopping Center Appraisal and Analysis, 2009
Subdivision Valuation, 2008
Valuation of Apartment Properties, 2007
Valuation of Billboards, 2006
Appraising Industrial Properties, 2005
Valuation of Market Studies for Affordable Housing, 2005
Valuing Undivided Interest in Real Property: Partnerships and Cotenancies, 2004
Analysis and Valuation of Golf Courses and Country Clubs, 2003
Valuing Contaminated Properties: An Appraisal Institute Anthology, 2002
Hotels and Motels: Valuation and Market Studies, 2001
Land Valuation: Adjustment Procedures and Assignments, 2001
Appraisal of Rural Property, Second Edition, 2000
Capitalization Theory and Techniques, Study Guide, Second Edition, 2000
Guide to Appraisal Valuation Modeling Land, 2000
Appraising Residential Properties, Third Edition, 1999
Business of Show Business: The Valuation of Movie Theaters, 1999
GIS in Real Estate: Integrating, Analyzing and Presenting Locational Information, 1998
Market Analysis for Valuation Appraisals, 1995

REPRESENTATIVE WORK OF MICHAEL S. MAROUS

Headquarters/Corporate Office Facilities in Illinois

Fortune 500 corporation facility, 200,000 sq. ft., Libertyville
Corporate headquarters, 300,000 sq. ft. and 500,000 sq. ft., Chicago
Fortune 500 corporation facility, 450,000 sq. ft., Northfield
Major airline headquarters, 1,100,000 million sq. ft. on 47 acres, Elk Grove Village
Former communications facility, 1,400,000 million sq. ft. on 62 acres, Skokie and Niles
Corporate Headquarters, 1,500,000+ sq. ft., Lake County
Former Sears Headquarters Redevelopment Project, Chicago

Office Buildings in Chicago

401 South LaSalle Street, 140,000 sq. ft.
134 North LaSalle Street, 260,000 sq. ft.
333 North Michigan Avenue, 260,000 sq. ft.
171 West Randolph Street, 360,000 sq. ft.
20 West Kinzie Street, 405,000 sq. ft.
55 East Washington Street, 500,000 sq. ft.
10 South LaSalle Street, 870,000 sq. ft.
222 West Adams Street, 1,000,000 sq. ft.
141 West Jackson Boulevard, 1,065,000 sq. ft.
333 South Wabash Avenue, 1,125,000 sq. ft.
155 North Wacker Drive, 1,406,000 sq. ft.
70 West Madison Street, 1,430,000 sq. ft.
111 South Wacker Drive, 1,454,000 sq. ft.
175 West Jackson Boulevard, 1,450,000 sq. ft.
227 West Monroe Street, 1,800,000 sq. ft.
10 South Dearborn Street, 1,900,000 sq. ft.

Hotels in Chicago

One West Wacker Drive (Renaissance Chicago Hotel)
10 East Grand Avenue (Hilton Garden Inn)
106 East Superior Street (Peninsula Hotel)
120 East Delaware Place (Four Seasons)
140 East Walton Place (The Drake Hotel)
160 East Pearson Street (Ritz Carlton)
301 East North Water Street (Sheraton Hotel)
320 North Dearborn Street (Westin Chicago River North)
401 North Wabash Avenue (Trump Tower)
505 North Michigan Avenue (Hotel InterContinental)
676 North Michigan Avenue (Omni Chicago Hotel)
800 North Michigan Avenue (The Park Hyatt)

Large Industrial Properties in Illinois

Large industrial complexes, 400,000 sq. ft., 87th Street and Greenwood Avenue, Chicago
Distribution warehouse, 580,000 sq. ft. on 62 acres, Champaign
Publishing house, 700,000 sq. ft. on 195 acres, U.S. Route 45, Mattoon
AM Chicago International, 700,000± sq. ft. on 41 acres, 1800 West Central Road, Mount Prospect
Nestlé distribution center, 860,000 sq. ft. on 153 acres, DeKalb
U.S. Government Services Administration distribution facility, 860,000 sq. ft., 76th Street and Kostner Avenue, Chicago
Fortune 500 company distribution center, 1,000,000 sq. ft., Elk Grove Village
Caterpillar Distribution Facility, 2,231,000 sq. ft., Morton
Self-storage facilities, various Chicago metropolitan locations

Airport Related Properties

Mr. MaRous has performed valuations on more than 100 parcels in and around Chicago O'Hare International Airport, Chicago Midway International Airport, Palwaukee Municipal Airport, Chicago Aurora Airport, DuPage Airport, and Lambert-St. Louis International Airport

Vacant Land in Illinois

15 acres, office, Northbrook
20 acres, residential, Glenview
25 acres, Hinsdale
55 acres, mixed-use, Darien
68 acres, Roosevelt Road and the Chicago River
75 acres, I-88 at I-355, Downers Grove
100± acres, various uses, Lake County
100 acres, Western Springs
140 acres, Flossmoor
142 acres, residential, Lake County
160 acres, residential, Cary
200 acres, mixed-use, Bartlett
250 acres, Island Lake
450 acres, residential, Wauconda
475± acres, various uses, Lake County
650 acres, Hawthorne Woods
650 acres, Waukegan/Libertyville
800 acres, Woodridge
900 acres, Matteson
1,000± acres, Batavia area
2,000± acres, Northern Lake County
5,000 acres, southwest suburban Chicago area
Landfill expansion, Lake County

Retail Facilities

20 Community shopping centers, various Chicago metropolitan locations
Big-box uses, various Chicago metropolitan locations and the Midwest
Gasoline Stations, various Chicago metropolitan locations
More than 50 single-tenant retail facilities larger than 80,000 sq. ft., various Midwest metropolitan locations

Residential Projects

Federal Square townhouse development project, 118 units, $15,000,000+ sq. ft. project, Dearborn Place, Chicago
Marketability and feasibility study, 219 East Lake Shore Drive, Chicago
Riverview II, Chicago; Old Town East and West, Chicago; Museum Park Lofts II, Museum Park Tower 4, University Commons, Two River Place, River Place on the Park, Chicago;
Timber Trails, Western Springs, Illinois

Market Impact Studies

Land-fill projects in various locations
Quarry expansions in Boone and Kendall counties
Commercial development and/or parking lots in various communities
Zoning changes in various communities
Waste transfer stations in various communities

Energy Projects

Oakwood Hills Energy Center, McHenry County Illinois, market impact analysis
Walnut Ridge Wind Farm, Bureau County, Illinois, market impact analysis
Twin Forks Wind Farm, Macon County, Illinois, market impact analysis
Twin Groves Wind Farm, McLean County, Illinois, market impact analysis
Otter Creek Wind Farm, LaSalle County, Illinois, market impact analysis
Pleasant Ridge Wind Farm, Livingston County, Illinois, consulting
Commonwealth Edison, high tension lines, market impact analysis
Lackawanna Power Plant, Lackawanna County, Pennsylvania, market impact analysis
Brookhaven, New York, solar energy production facility, consulting

Business and Industrial Parks

Chevy Chase Business Park, 30 acres, Buffalo Grove
Carol Point Business Center, 300-acre industrial park, Carol Stream, $125,000,000+ project
Internationale Centre, approximately 1,000 acre-multiuse business park, Woodridge

Properties in Other States

330,000 sq. ft., Newport Beach, California
Former government depot/warehouse and distribution center, 2,500,000 sq. ft. on 100+ acres, Ohio
Shopping Center, St. Louis, Missouri
Office Building, Clayton, Missouri
Condominium Development, New York, New York
Hormel Foods, various Midwest locations
Wisconsin Properties including Lowes, Menards, Milwaukee Zoo, CVS Pharmacys in Milwaukee, Dairyland Race Track, Major Industrial Property in Manawa , Class A Office Buildings and Vacant Land

REPRESENTATIVE CLIENT LISTING OF MICHAEL S. MAROUS

Law Firms

Alschuler, Simantz & Hem LLC
Ancel, Glink, Diamond, Bush, DiClanni & Krafthefer
Arnstein & Lehr LLP
Berger, Newmark & Fenchel P.C.
Berger Schatz
Botti Law Firm, P.C.
Carmody MacDonald P.C.
Carr Law Firm
Crane, Heyman, Simon, Welch & Clar
Daley & Georges, Ltd.
Day, Robert & Morrison, P.C.
Dentons US LLP
DiMonte & Lizak LLC
DLA Piper
Dreyer, Foote, Streit, Furgason & Slocum, P.A.
Drinker, Biddle & Reath LLP
Figliulo & Silverman, P.C.
Foran, O'Toole & Burke LLC
Franczek Radelet P.C.
Fredrikson & Byron, P.A.
Freeborn & Peters LLP
Gould & Ratner LLP
Greenberg Traurig LLP
Helm & Wagner
Robert Hill Law, Ltd.
Hinshaw & Culbertson LLP
Holland & Knight LLP
Ice Miller LLP
Jenner & Block
Katz & Stefani, LLC
Kinnally, Flaherty, Krentz, Loran, Hodge & Mazur PC
Kirkland & Ellis LLP
Klein, Thorpe & Jenkins, Ltd.
McDermott, Will & Emery
Mayer Brown
Michael Best & Friedrich LLP
Morrison & Morrison, Ltd.
Bryan E. Mraz & Associates
Neal, Gerber & Eisenberg, LLP
Neal & Leroy LLC
O'Donnell Haddad LLC
Prendergast & DelPrincipe
Rathje & Woodward, LLC
Righeimer, Martin & Cinquino, P.C.
Robbins, Salomon & Patt, Ltd.
Rosenfeld Hafron Shapiro & Farmer
Rosenthal, Murphey, Coblentz & Donahue
Rubin & Associates, P.C.
Ryan and Ryan, P.C.
Reed Smith LLP
Sarnoff & Baccash
Scariano, Himes & Petrarca, Chtd.
Schiff Hardin LLP
Schiller, DuCanto & Fleck LLP
Schirott, Luetkehans & Garner, LLC
Schuyler, Roche & Crisham, P.C.
Sidley Austin LLP
Storino, Ramello & Durkin
Thomas M. Tully & Associates
Thompson Coburn, LLP
Tuttle, Vedral & Collins, P.C.
Vedder Price
von Briesen & Roper, SC
Winston & Strawn LLP
Worsek & Vihon LLP

Financial Institutions

AmericaUnited Bank Trust
BMO Harris Bank
Charter One
Citibank
Cole Taylor Bank
First Bank of Highland Park
First Financial Northwest Bank
First Midwest Bank
First State Financial
Glenview State Bank
Itasca Bank & Trust Co.
Lake Forest Bank & Trust Co.
MB Financial Bank
Midwest Bank
Northern Trust
Northview Bank & Trust
The Private Bank
Wintrust

Corporations

Advocate Health Care System
Alliance Property Consultants
American Stores Company
Archdiocese of Chicago
Arthur J. Rogers and Company
Avangrid Renewables, LLC
BHE Renewables
BP Amoco Oil Company
Christopher B. Burke Engineering, Ltd.
Cambridge Homes
Canadian National Railroad
Capital Realty Services, Inc.
Chicago Cubs
Children's Memorial Hospital
Chrysler Realty Corporation
Citgo Petroleum Corporation
CorLands
CVS
Edward R. James Partners, LLC
Enterprise Development Corporation
Enterprise Leasing Company
Exxon Mobil Corporation
Hamilton Partners
Hollister Corporation
Imperial Realty Company
Invenergy LLC
Kimco Realty Corporation
Kinder Morgan, Inc.
Lakewood Homes
Lowe's Companies, Inc.
Loyola University Health System
Marathon Oil Corporation
Meijer, Inc.
Menards
Mesirow Stein Real Estate, Inc.
Paradigm Tax Group
Prime Group Realty Trust
Public Storage Corporation
RREEF Corporation
Shell Oil Company
Union Pacific Railroad Company
United Airlines, Inc.

Public Entities

Illinois Local Governments and Agencies

Village of Arlington Heights
Village of Barrington
Village of Bartlett
Village of Bellwood
Village of Brookfield
Village of Burr Ridge
City of Canton
Village of Cary
City of Chicago
Village of Deer Park
City of Des Plaines
Des Plaines Park District
Downers Grove Park District
City of Elgin
Elk Grove Village
City of Elmhurst
Village of Elmwood Park
City of Evanston
Village of Forest Park
Village of Franklin Park
Village of Glenview
Glenview Park District
Village of Harwood Heights
City of Highland Park
Village of Hinsdale
Village of Inverness
Village of Kenilworth
Village of Kildeer
Village of Lake Zurich
Leyden Township
Village of Lincolnshire
Village of Lincolnwood
Village of Morton Grove
Village of Mount Prospect
Village of North Aurora
Village of Northbrook
City of North Chicago
Village of Northfield
Northfield Township
Village of Oak Brook
Village of Orland Park
City of Palos Hills
City of Peoria
City of Prospect Heights
City of Rolling Meadows
Village of Rosemont
City of St. Charles
Village of Schaumburg
Village of Schiller Park
Village of Skokie
Village of South Barrington
Village of Streamwood
Metropolitan Water Reclamation District of Greater Chicago
City of Waukegan
Village of Wheeling
Village of Wilmette
Village of Willowbrook
Village of Winnetka
Village of Woodridge

County Governments and Agencies

Boone County State's Attorney's Office
Forest Preserve of Cook County
Cook County State's Attorney's Office
DuPage County Board of Review
Forest Preserve District of DuPage County
Kane County
Kendall County Board of Review
Lake County
Lake County Forest Preserve District
Lake County State's Attorney's Office
Morton Township
Peoria County

State and Federal Government Agencies

Federal Deposit Insurance Corporation
U.S. General Services Administration
Illinois Housing Development Authority
Illinois State Toll Highway Authority
Internal Revenue Service
The U.S. Postal Service

Schools

Argo Community High School District No. 217
Arlington Heights District No. 25 Township High School District No. 214, Arlington Heights
Barrington Community Unit District No. 220
Chicago Board of Education
Chicago Ridge District No. 127½
College of Lake County
Community Consolidated School District No. 15
Community Consolidated School District No. 146
Community School District No. 200
Consolidated High School District No. 230
Darien District No. 61
DePaul University
Elk Grove Community Consolidated District No. 59
Elmhurst Community Unit School District No. 205
Glen Ellyn School District No. 41
Glenbard High School District No. 87
Indian Springs School District No. 109
LaGrange School District No. 105
Lake Forest Academy
Leyden Community High School District No. 212
Loyola University
Lyons Township High School District No. 204
Maine Township High School District No. 207
Niles Elementary District No. 71
North Shore District No. 112, Highland Park
Northwestern University
Orland Park School District No. 135
Palatine High School District #211
Rhodes School District No. 84-1/2
Riverside-Brookfield High School District No. 208
Rosalind Franklin University
Roselle School District No. 12
Schaumburg Community Consolidated District No. 54
Sunset Ridge School District No. 29
Township High School District No. 211
Township High School District No. 214
Triton College
University of Illinois
Wheeling Community Consolidated District No. 21
Wilmette District No. 39

JOSEPH M. MAROUS
STATEMENT OF QUALIFICATIONS

Joseph M. MaRous is an Associate Appraiser with MaRous and Company, with a focus on the renewable and alternative energy industry.

EDUCATION

Purdue University - West Lafayette, Indiana

Bachelor of Science – Building Construction Management

Focus in residential and green build construction

CERTIFICATIONS

Certified Green Build Professional

OSHA Safety Certified

USPAP Certified

CONSTRUCTION

Professional in the construction industry for 10 years

- Residential
- Commercial
- Industrial
- Municipal
- Tenant Improvement
- Schools
- Media Studios
- Automobile Dealerships

APPRAISAL

Wind Projects
- Illinois
- Iowa
- South Dakota
- New York

Solar Projects
- Maryland
- Wisconsin

- Vacant Land
- Auto Dealerships
- Religious Facilities
- Residential
- Commercial
- Retail

For more details visit: linkedin.com/in/joemarous

WIND ENERGY BENEFITS TO LOCAL COMMUNITIES

APEX CLEAN ENERGY

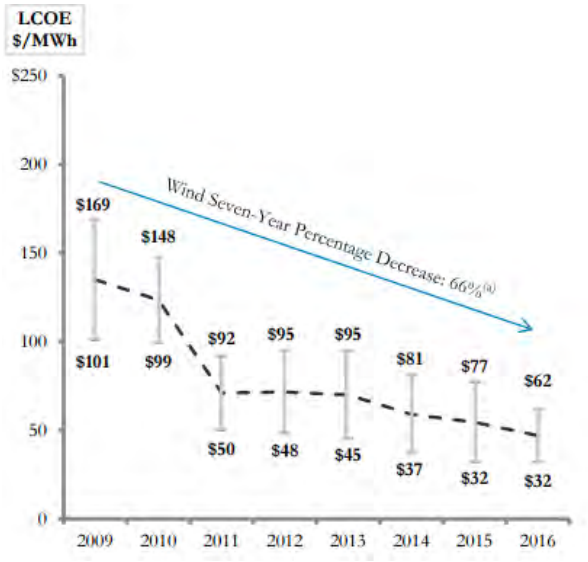
WIND ENERGY FACTS

Fact: Currently installed wind energy produces enough electricity to power more than 24 million homes.

Wind power delivered 30% of all new capacity installed over the past five years.[1]

Fact: Wind energy helps consumers save money.

The cost of electricity from wind has dropped 66% in the past seven years (see right). New Department of Energy data shows that utility customers in the 11 states with the most wind energy installed have saved more on their electric bills than customers in other states.[2]



Source: Lazard, "Lazard's Levelized Cost of Energy Analysis," Version 10.0 (2016).

Fact: Wind energy is reliable

Wind energy delivered over 30% of the electricity produced in Iowa and South Dakota in 2016. Kansas, Oklahoma, and North Dakota generated over 20% of their electricity from wind, while 20 states now produce more than 5% of their electricity from wind. [3]

Fact: Wind farms have a limited impact on birds.

Wind farms cause far fewer bird deaths than transmission lines and other traditional energy sources. All wind projects must comply with wildlife agency permit standards. According to a National Academy of Sciences study, wind turbines contribute to less than 0.0003% of human-caused bird fatalities.[4]

Fact: Courts around the world have dismissed cases regarding health effects of wind turbines.

Since 1998, 49 cases have been heard in at least five countries regarding health effects caused by wind turbines. Forty-eight cases have been dismissed due to the fact that there was no reliable evidence that sound and shadow flicker from wind turbines made people sick.[5]

Fact: Wind energy incentives are smaller than those given to other energy sources.

Since 1950, 70% of all energy subsidies have gone to conventional fuel sources. As recently as 2002–2007, conventional sources received nearly five times as much in tax incentives as renewables.[6] The PTC (production tax credit) is being phased out over the next few years.

Fact: Wind farms do not affect property values of nearby homes.

Several studies have shown this to be true, including one by Lawrence Berkeley National Laboratory that studied 50,000 U.S. home sales near 67 wind facilities in 27 counties and found no evidence that home values were affected.[7]

SOURCES

1. AWEA Annual Market Report 2016
2. https://www.lazard.com/perspective/levelized-cost-of-energy-analysis-100/
3. AWEA Annual Market Report 2016
4. http://www.nap.edu/openbook.php?record_id=11935&page=71.
5. http://www.energyandpolicy.org/wind-health-impacts-dismissed-in-court
6. http://www.nei.org/Master-Document-Folder/Backgrounders/White-Papers/60-Years-of-Energy-Incentives-Analysis-of-Federal; http://www.gao.gov/new.items/d08102.pdf.
7. http://emp.lbl.gov/sites/all/files/lbnl-6362e.pdf

info@apexcleanenergy.com | 434.220.7595 | apexcleanenergy.com

APEX CLEAN ENERGY

The Facts About Wind Development in South Dakota

South Dakota Wind Energy Association SDWEA

Legislator Brief and Talking Points

Wind Energy Works for South Dakota

When revenue for agriculture and the state is low, look to wind development to provide a cash crop of opportunity. In 2016, the state generated more than 26.9 percent of its electricity from wind power, third in the nation, while the future is full of possibility as the fifth windiest state, South Dakota has a significant wind resource potential.

Top Five States, #1 Iowa: 35.8%, #2 Kansas: 27.7%. **#3 SD: 26.9%,** #4 Oklahoma: 23.3 and #5 North Dakota: 19.8. *AWEA July 2016*

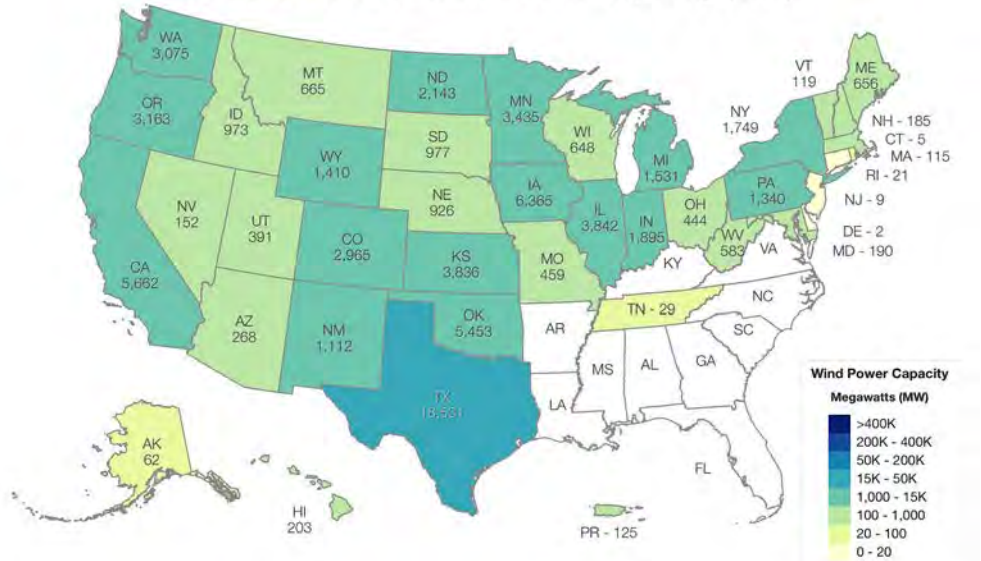
Wind Project Statistics

- Installed wind capacity: **977 MW**
- State rank for installed wind capacity: **18th**
- Number of wind turbines: **583**
- State rank for number of wind turbines: **18th**
- Number of wind projects online: **14**
- Land area suitable for wind resource development: **94%**
- Wind manufacturing facilities: **five**
- High-quality wind capacity (wind blowing at full capacity) is **40% (3rd in nation)**
- Rank for fastest growing wind economy: **10th**

Current South Dakota wind generation with installed capacity

- Equivalent number of homes powered by wind: Over 227,000.

Q3 2016 Installed Wind Power Capacity (MW)

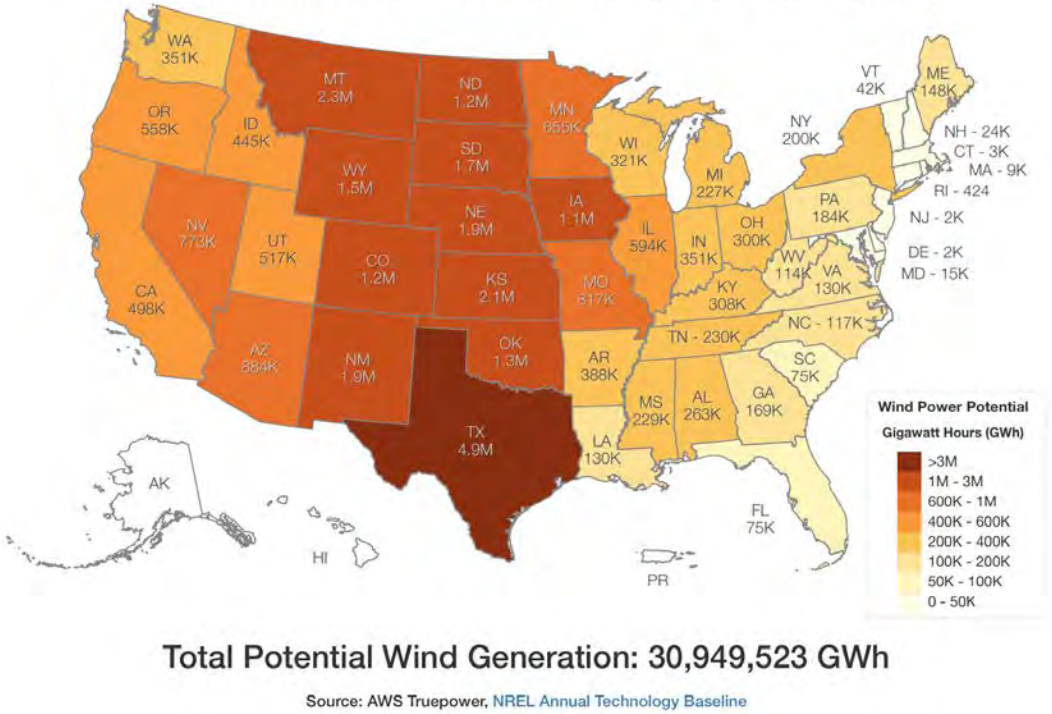


Total Installed Wind Capacity: 75,714 MW

Source: American Wind Energy Association Q3 2016 Market Report

Potential of Wind Energy Production

U.S. Potential Wind Generation in Gigawatt Hours (GWh)



Total Potential Wind Generation: 30,949,523 GWh

Source: AWS Truepower, NREL Annual Technology Baseline

Wind Generation Potential

The US Department of Energy Wind Vision Scenario projects that South Dakota could produce enough wind energy by 2030 to power the equivalent of 895,000 average American homes. Looking toward 2050, there is potential to provide 80 percent of the nation's electricity by 2050.

Wind Energy and the Advantages for Policy and Economic Growth

- **Wind turbine technician** is one of America's fastest growing jobs. The Bureau of Labor Statistics says the occupation will grow by 108 percent over the next decade. Local educational programs at Mitchell Technical Institute and Lake Area Technical Institute offer this profession for SD students.
- Americans and South Dakotans love wind power. Poll after poll in 2016, showed **strong bipartisan support for wind energy growth**. 83 percent of Americans want to see more wind, according to a recent Pew poll, just one data point among many that confirmed wind's popularity crosses both geographical and political lines.
- Across the country, a number of state governments **strengthened their renewable portfolio standards (RPS)** to bring more low-cost, clean wind energy to millions of families and businesses.
- Many of the **largest Fortune 500 companies**, including Google, Bank of America, General Motors, Microsoft, Amazon, Starbucks, Walmart and Nike, are making renewable resources a priority and are **demanding clean energy** in determining where they locate their facilities and create jobs. Wind energy is a big part of this plan and many states are eager for the chance to entice these companies' and gain the economic benefits that are associated.

Truths about Wind Power and Project Development

Wind power is one of the oldest forms of natural energy: Wind mills have been in use since 2000 B.C. and were first developed in China and Persia.

The settlers used windmills to water their livestock and irrigate crops. Since 2009, South Dakota has built and benefited from the power of modern wind energy development, that is recognized as one of the safest and most environmentally friendly forms of electricity generation.

As an agricultural state, wind power is considered a cash crop when other forms of revenue are low, and for counties that rely on farming and ranching, wind projects are a boom for the local economy.

Wind Turbine and Power Facts

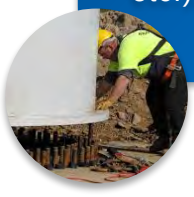
- Most wind turbines (98.7%) are installed on private land.
- Modern wind turbines produce 19 times more electricity than typical turbines in 1990.
- On average, a single wind turbine can power 500 homes.
- Wind power was the top source for new electric capacity last year in the U.S., comprising 35% of all new U.S. electric capacity additions.
- Wind energy prices have dropped 66 % since 2009. Lower wind turbine prices and installed project costs, along with improved capacity factors, are enabling aggressive wind power pricing.

A strong rural economy is built on three pillars: natural amenities, natural resources, and manufacturing. Unfortunately, these pillars are no longer as strong as they once were and as a result, it is critical for rural economies to diversify. Many jobs can now be found in the service sector to include education, health care and retail trade to support families, states the *U.S. Department. of Energy.* Wind energy projects offer South Dakota communities an opportunity to reinforce the pillars.

These projects are made possible by unique attributes South Dakota's rural counties can offer: a combination of renewable resources; sparsely populated tracts of land; and a strong work force.

Direct Project Impacts

- On Site: Construction workers, management and administrative support, truck drivers, road crews and maintenance workers.
- Off Site: Boom truck, gas stations, manufacturers (blades, towers, turbines, etc.), and hardware/parts store suppliers



Indirect Impacts

- Jobs and payments made to supporting businesses, such as bankers, financing the construction, contractors and equipment suppliers.

Induced Impacts

- Jobs and earnings from the spending by people directly and indirectly supported by the project, including grocery store clerks, retail salespeople, and child care providers.

Benefits of Wind Energy Development

Being A Power Source isn't the Only Impact of Wind

An investment in wind power is an investment in jobs, local revenue, lower utility costs, public health, the environment, and wildlife. The wind industry pays taxes to local communities, providing added revenue for hospitals, schools, roads, and other public services.

- Wind projects include jobs in operations and maintenance, construction, manufacturing and many support sectors. In addition, wind projects produce lease payments for landowners and increase the tax base of communities which assists local school districts.

- The generation of wind provides a domestic, sustainable, and economically viable energy source as it reduces consumer electricity prices, helps protect against future price shocks and allows the market to be more competitive.

- Wind deployment delivers public health and environmental benefits, including reduced greenhouse gases (GHG) emissions, reduced air pollutants, and lower water consumption and withdrawals.

The building of wind facilities is done with careful consideration for the public's acceptance of land use, wildlife concerns and radar interference using planning, technology, and communication to mitigate issues and improve upon study results.

SD's Impact and Benefits

- Jobs supported over last two years: **1,001 to 2,000**
- Total capital investment: **$2 billion**
- Annual land lease payments: Over **$2.4 million**
- Annual state water consumption savings: **262 million gallons**
- Equivalent number of water bottles saved: **1.9 billion**
- Carbon dioxide (CO_2) emissions avoided: **480,000 metric tons** and equivalent cars worth of emissions avoided: **96,000**
- South Dakota's population suffering from asthma and other respiratory diseases (CDC, 2015): Over **97,000** or **11%**.

South Dakota Wind Energy Association SDWEA

Annual Membership Form

Name:_____Title:_____

Organization:_____ Address:_____

City:_____ State:_____Zip Code:_____Phone:_____

Email:_____

Membership Levels: Please circle preferred membership level at right. Payment can be submitted by check or through PayPal by account or credit card. Go to sdwea.org, members page. For more information or questions, call 605-679-7920 or office@sdwea.org

Mail to: SDWEA, 300 East Capitol, Pierre, SD 57501

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ECONOMIC DEVELOPMENT IMPACTS OF WIND PROJECTS

JOBS AND ECONOMIC IMPACTS RESULTING FROM U.S. WIND PROJECTS 2017-2020

Prepared for:

MARCH 2017

NAVIGANT

REPORT CONTENTS

1 Executive Summary

2 Wind MW Forecast

3 Wind Jobs Impact

4 Economic Impact

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EXECUTIVE SUMMARY » SCOPE

Navigant evaluated the economic impact of U.S. wind projects for the period 2017 through 2020.

Scope of Study

» For each state and year, we produced a forecast of the following items:
- Wind MW installed
- Wind jobs (direct, indirect, and induced)
  - Manufacturing
  - Construction
  - Operations & Maintenance
- Economic impact
  - Manufacturing (direct, indirect, and induced)
  - Construction (direct, indirect, and induced)
  - Other (land lease payments, federal, state, and local taxes)

» The forecast assumes no change in the current Production Tax Credit (PTC) policy
- The Clean Power Plan will not be implemented at the national level but some states will proceed with similar plans for reductions in CO_2 emissions.

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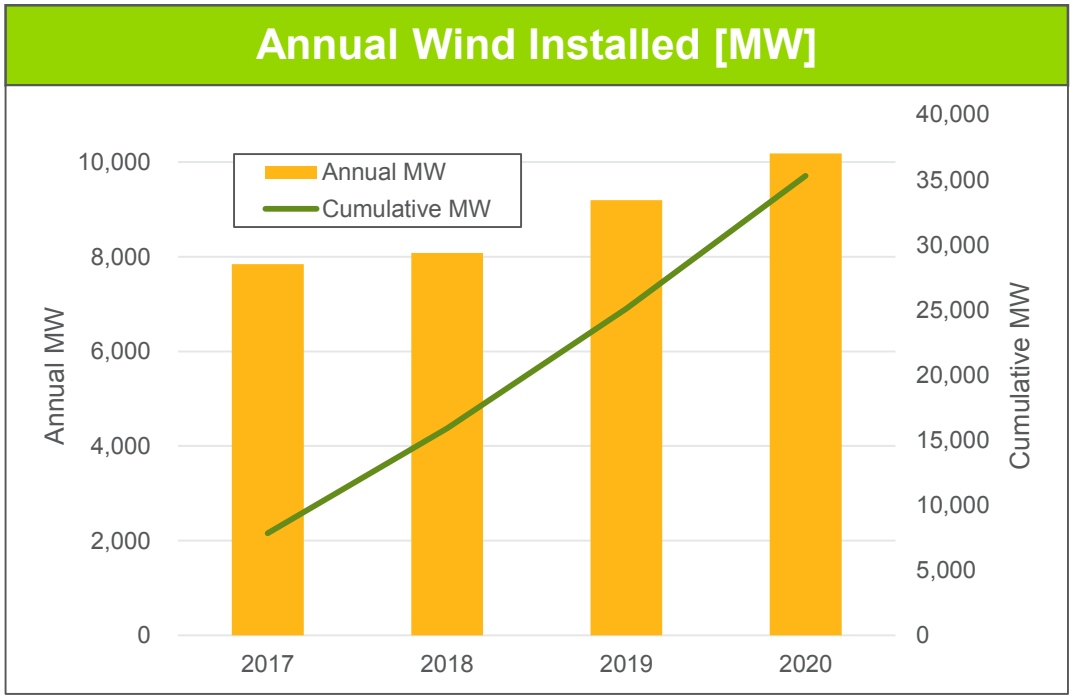
EXECUTIVE SUMMARY » MW FORECAST

The U.S. wind market will be in the 8-10 GW/year range through 2020.



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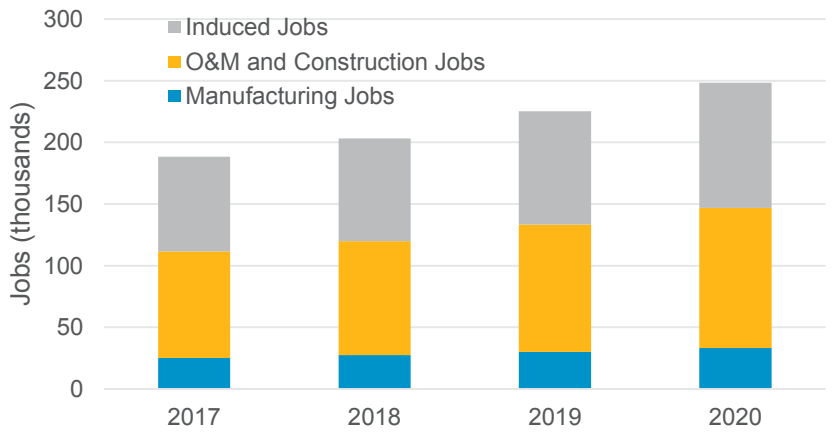
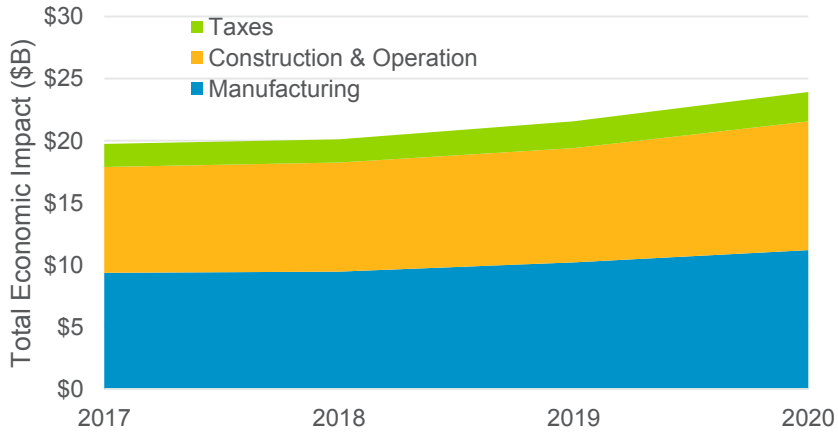
EXECUTIVE SUMMARY » EMPLOYMENT AND ECONOMIC IMPACT

Total U.S. wind employment will reach 248,000 jobs in 2020. Total new wind economic impact will peak at $24 billion in the same year.

Annual Wind Jobs [thousands of jobs]



Annual Wind Economic Impact [$B]



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EXECUTIVE SUMMARY » CONCLUSIONS

The U.S. wind market will continue to grow through 2020, largely due to the extension of the Production Tax Credit.

Conclusions
Wind MW Forecast – **35 GW of new wind capacity will be installed in 2017-2020.** » Annual wind installations will reach 10 GW in 2020. Wind Employment and Economic Impact – **The U.S. wind industry will support 865,000 job-years of employment and provide $85 billion in economic impact in 2017-2020.** » Annual employment will reach 248,000 jobs in 2020. » Annual new economic impact will reach $24 billion in 2020.

Total Impacts on the U.S. Wind Market 2017-2020	
New wind installed [GW]	35
Total wind jobs (direct, indirect, and induced) [job-years]	865,000
Total wind economic impact [2016$]	$85 billion

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WIND MW FORECAST » METHODOLOGY

Navigant used a combination of sources and techniques to develop the U.S. wind MW forecast.

a. *Bottom-up forecast* – a probabilistic forecast on a project-by-project basis
   - The bottom-up analysis was the primary source for 2017

b. *Industry interviews* – a consensus forecast of major U.S. wind developers and manufacturers
   - Industry interviews were the primary sources in the 2018-2020 forecast

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WIND MW FORECAST » METHODOLOGY

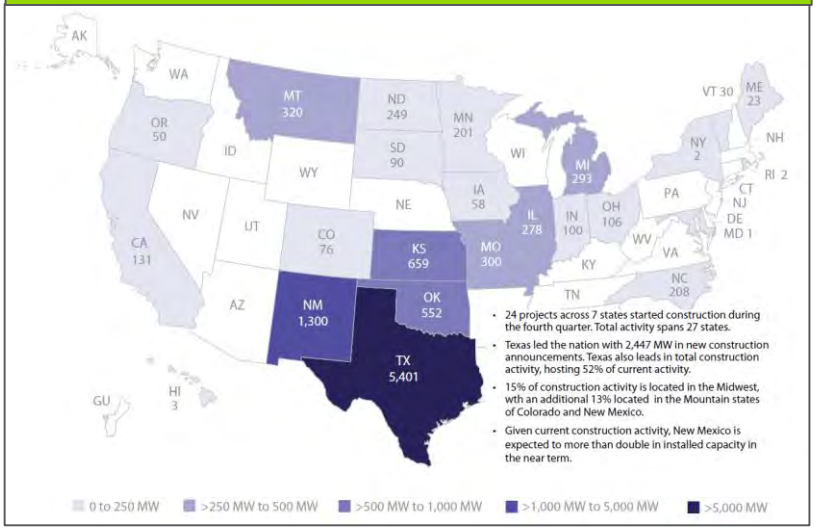
The bottom-up forecast and the distribution by state for 2017-2020 were based on AWEA's project data base.

Total U.S. Wind Capacity Under Construction or Development [MW]

Expected Year of Completion	Under Construction	Under Development	Total
2017	5,979	2,876	8,855
2018	2,169	2,210	4,379
2019	731	2,557	3,288
2020	1,050	650	1,700
Total	9,929	8,292	18,221

Source: AWEA, January 2017

U.S. Wind Capacity Under Construction [MW]



Source: AWEA, U.S. Wind Industry Fourth Quarter 2016 Market Report

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WIND MW FORECAST » METHODOLOGY

Navigant interviewed 12 leading U.S. wind developers and manufacturers to develop a consensus forecast.

Summary of Survey Questions		
	Developers	Manufacturers
What is your company's view of the 2017-2023 U.S. wind market (in new installed capacity)?	X	X
How many MW per year of wind capacity does your company expect to install in the U.S. in 2017-2019?	X	
In 2016, how many FTE employees directly work in your company for the wind industry, located in the U.S.?		X
Would your company plan to change its manufacturing capacity in the U.S. and adjust your number of employees? How many people will be employed between 2017 and 2023?		X
What is the relationship between MW of wind turbines ordered and employment in your company in the U.S.? In other words, if your volume of business in the U.S. doubled, what percentage of increase in employment in the U.S. would result?		X
Of your existing workforce, what percentage of people are supporting new wind turbine manufacturing segment of the market? What activities do the remaining workers support?		X
For the U.S. wind market, what is the combined market share for *domestically-produced* components in your equipment segment? How do you expect that percentage to change between now and 2023?		X

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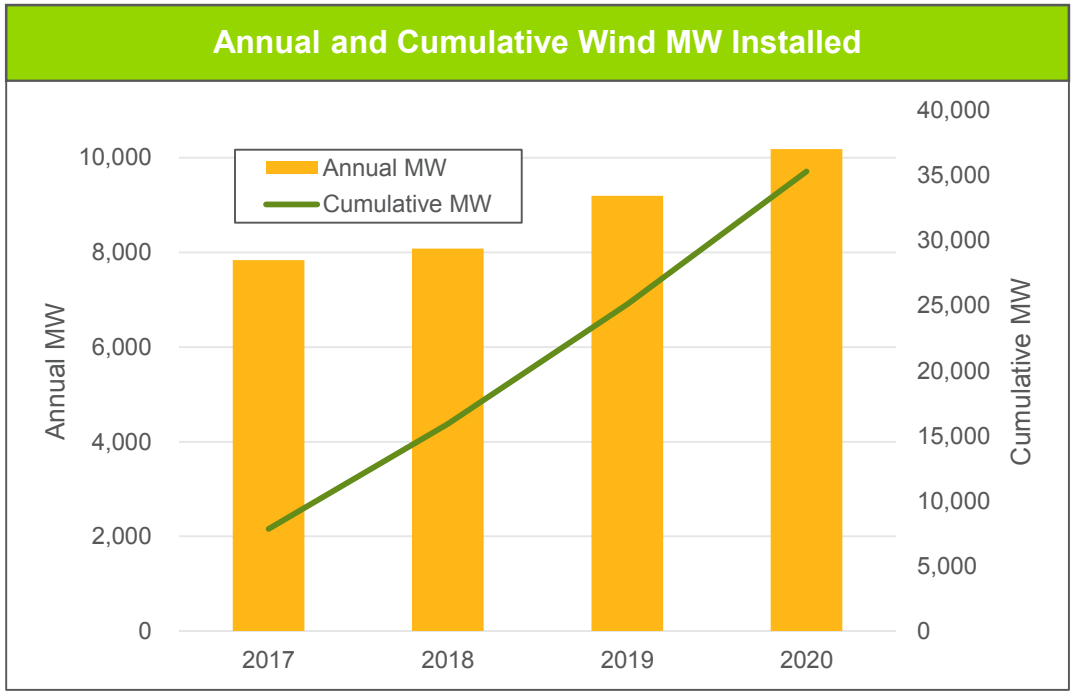
WIND MW FORECAST » RESULTS

There will be 35 GW of new U.S. wind installations in 2017-2020.



	2017	2018	2019	2020
Annual MW	7,839	8,078	9,195	10,182
Cumulative MW	7,839	15,917	25,112	35,294

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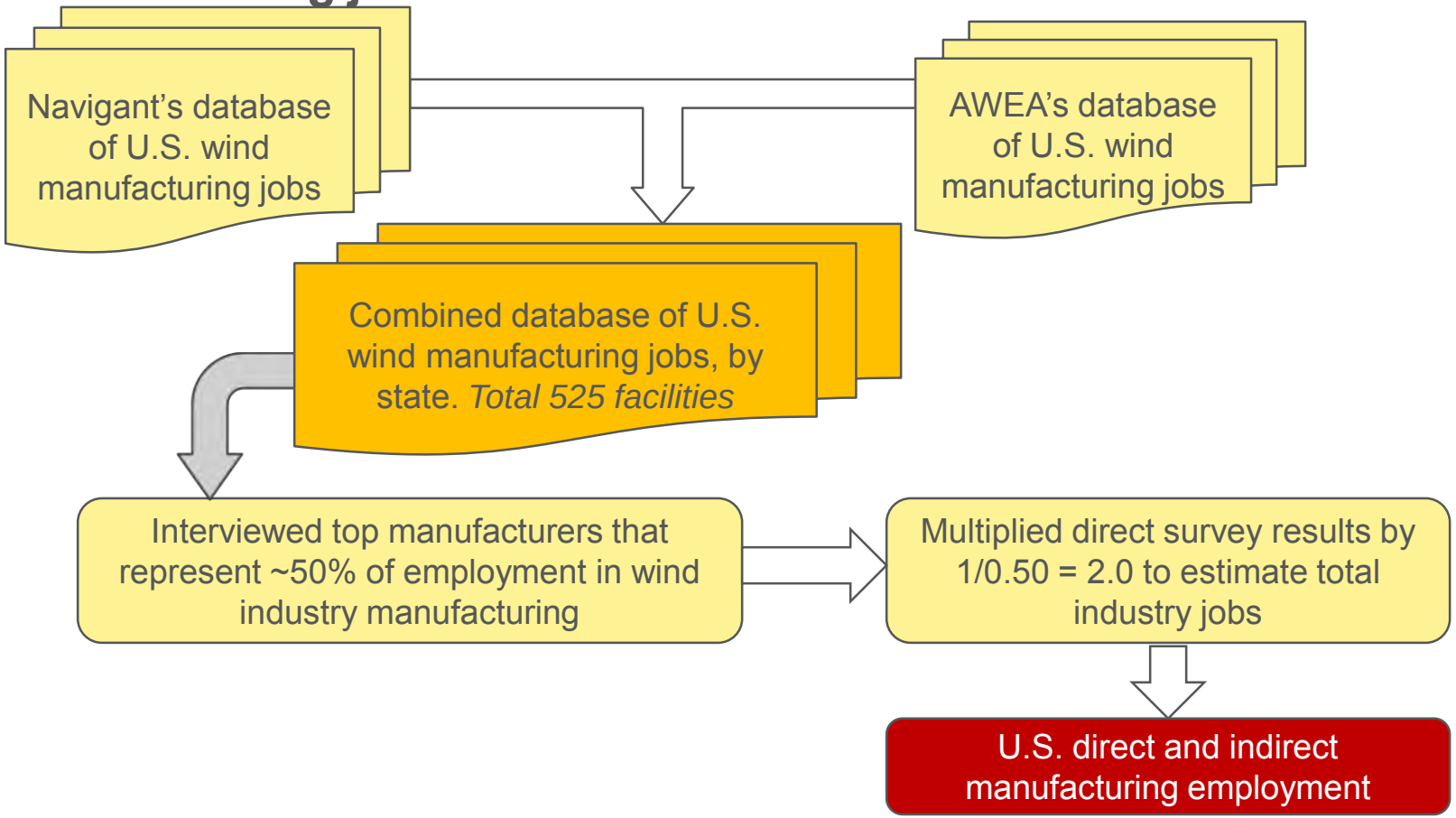
MANUFACTURING EMPLOYMENT

Navigant developed a bottom-up forecast of U.S. wind manufacturing jobs.



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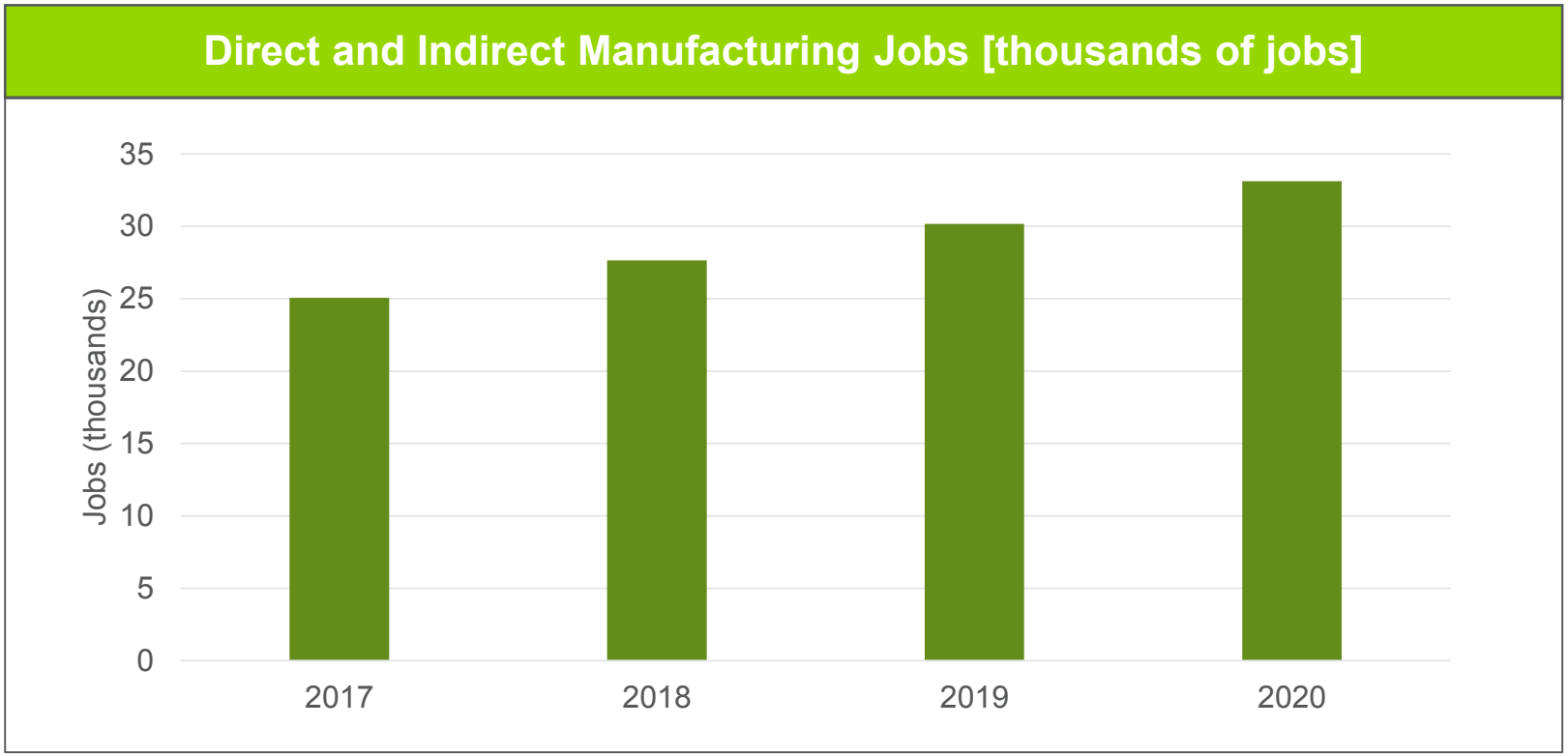
DIRECT AND INDIRECT MANUFACTURING EMPLOYMENT

U.S. direct and indirect wind manufacturing employment will increase to 33,000 jobs in 2020, primarily due to the extension of the PTC.



Source: Navigant, February 2017

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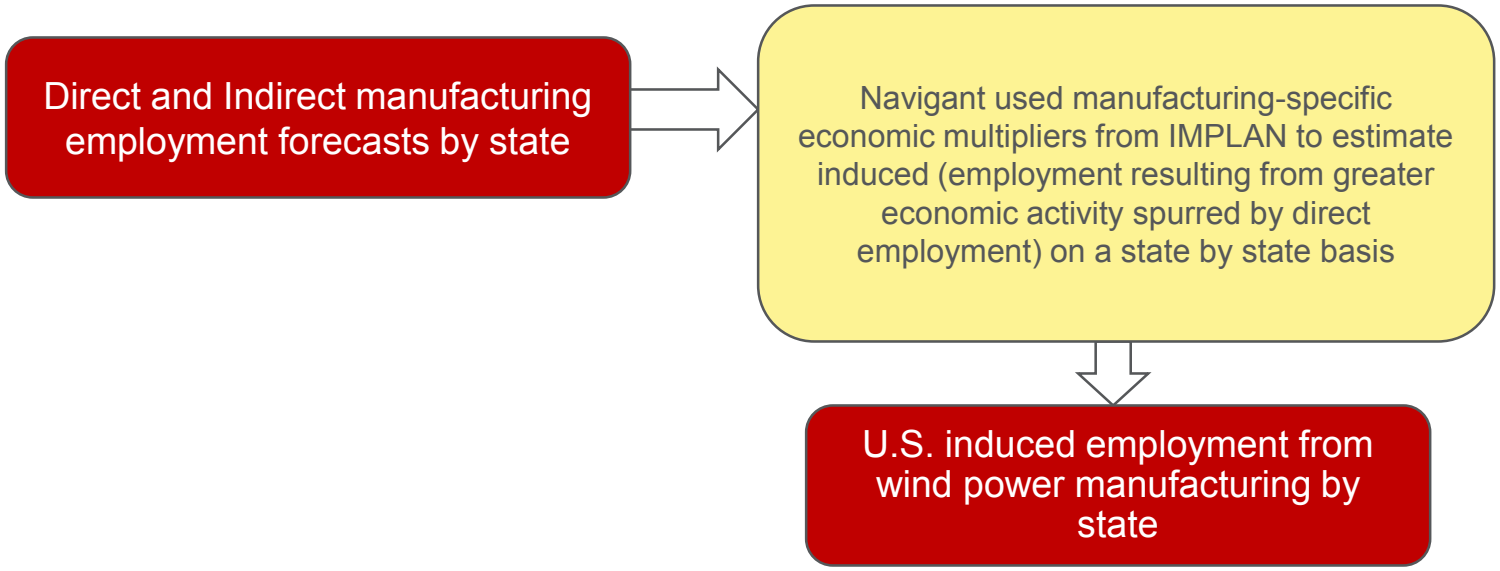
INDUCED MANUFACTURING EMPLOYMENT

Navigant calculated induced wind manufacturing jobs by using economic multipliers.



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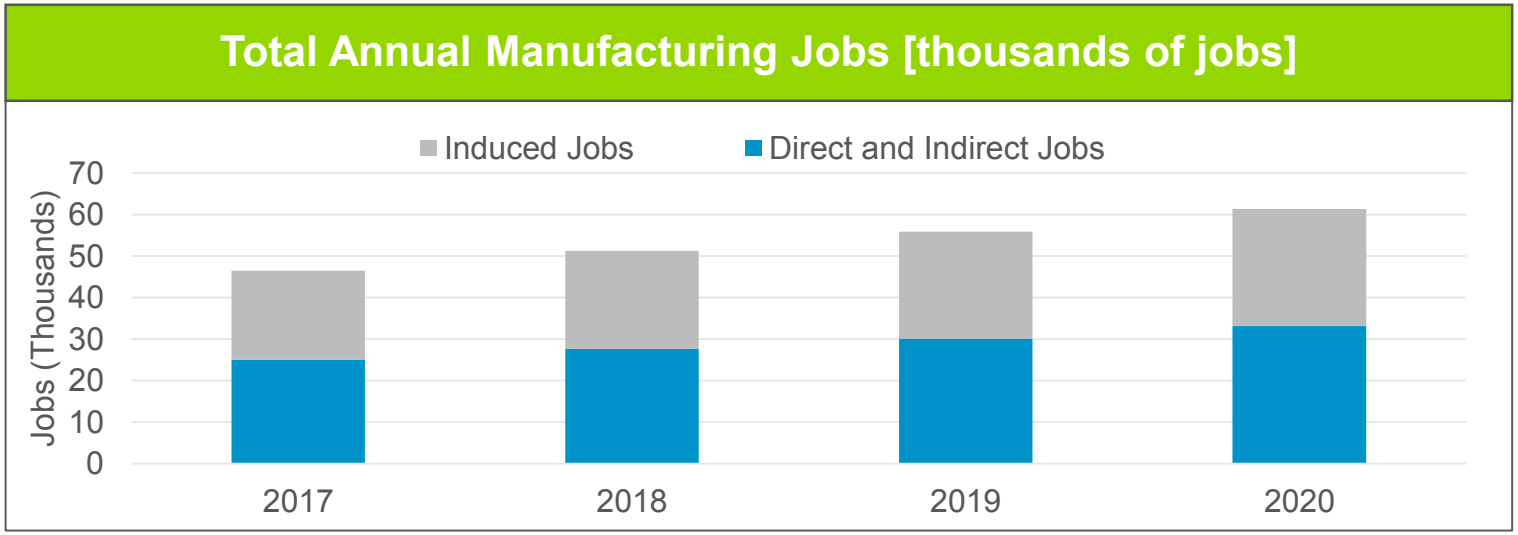
TOTAL MANUFACTURING EMPLOYMENT

Total annual manufacturing employment (direct, indirect, and induced) will grow to over 60,000 jobs in 2020.



[thousands of jobs]	2017	2018	2019	2020	2017-2020 (1)
Direct and Indirect Jobs	25	28	30	33	116
Induced Jobs	21	24	26	28	99
Total Jobs	46	51	56	61	215

1. 2017-2020 figures are in thousands of job-years

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CONSTRUCTION / INSTALLATION AND O&M EMPLOYMENT

Navigant used NREL's wind jobs & economic development impact (JEDI) model to assess labor impacts of installation and operation.

Navigant's Use of the JEDI[1] Model

- The land-based wind JEDI model was developed for the U.S. Department of Energy to analyze the economic benefits of constructing and operating wind power plants.
- JEDI contains wind power manufacturing and construction labor intensity data and then uses IMPLAN modeling software to project indirect and induced economic impacts. More information on IMPLAN modeling software can be found at http://www.implan.com/.
- Navigant conducted JEDI runs for each year 2017-2020 for the United States using the state-by-state wind new installations for construction jobs and state-by-state cumulative installations for operations jobs.

Source: NREL's JEDI model can be found at http://www.nrel.gov/analysis/jedi/

Notes:

1. The JEDI model used for this study is "Release Number: W06.23.16"
2. MRG & Associates provided national multipliers derived from the IMPLAN Version 3.0 Social Accounting & Impact Analysis Software. The multipliers cover employment, earnings, output, and personal consumption expenditure (PCE) patterns.

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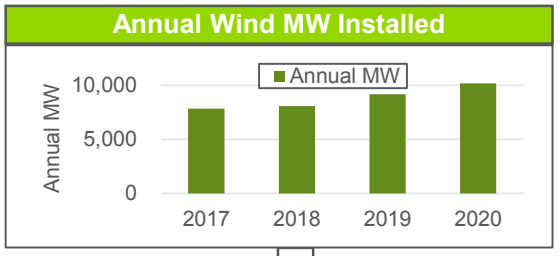
CONSTRUCTION / INSTALLATION EMPLOYMENT

Navigant used the JEDI model to calculate direct, indirect, and induced construction impacts based on the annual MW forecast.



Year	Total Installed Costs $/kW [1]
2017	1,666
2018	1,657
2019	1,648
2020	1,640

JEDI model[2]

State multipliers & locational cost-adjustment factors

U.S. direct, indirect, and induced employment from wind power construction/installation [3]

Notes:

- Blade, turbine, and tower manufacturing are excluded from indirect employment and included in Manufacturing employment.

Notes:

1. Total installed cost estimates are in 2015$ based on LBNL's 2015 Wind Technologies Market Report and NREL's 2016 Annual Technology Baseline report and converted to 2016$ for analysis
2. Local content for construction and O&M equipment and labor (excl. turbines, towers, and blades) based on JEDI default.
3. National impacts modeled with "US" JEDI region. State-specific impacts modeled using the state region in JEDI.

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OPERATIONS & MAINTENANCE EMPLOYMENT

Navigant used AWEA estimates to represent existing wind O&M jobs from the current 2016 installed base.

AWEA Job Estimates 2016	
Job Function	**No. of Jobs [1]**
Operations - Wind Technicians	9,800
Operations - Other [2]	12,300
Operations - Finance & Offsite Supply Chain [3]	15,500
Other [4]	4,000
Total Existing O&M Jobs (Direct & Indirect)	41,600

Navigant assumed all existing O&M employment will continue through the forecast period as these jobs support wind installations currently in operation.

Notes:
1. Job categories and estimates are from AWEA's 2016 Annual Report (currently unpublished).
2. Includes direct and indirect jobs, e.g. field and regional managers, and control room operators.
3. Includes indirect jobs, e.g. project finance, legal, and insurance. Also includes offsite supply chain including component repair and refurbishment.
4. Includes indirect jobs.

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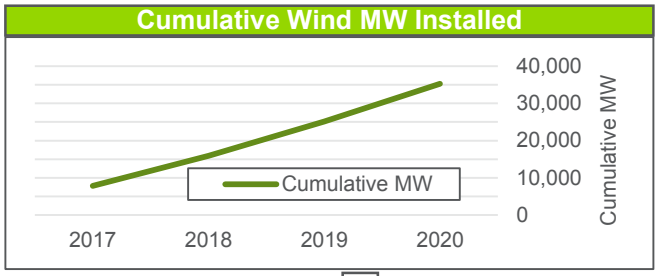
OPERATIONS & MAINTENANCE EMPLOYMENT

Navigant used the JEDI model to calculate new direct, indirect, and induced wind O&M jobs based on the cumulative MW forecast.



Year	Operating Costs $/kW-year [1]
2017	51.12
2018	50.84
2019	50.57
2020	50.29

JEDI model[2]

State multipliers & locational cost-adjustment factors

U.S. direct, indirect, and induced employment from wind power operation and maintenance [3]

Notes:

1. Total operating cost estimates are in 2015$ based on LBNL's 2015 Wind Technologies Market Report and NREL's 2016 Annual Technology Baseline report and converted to 2016$ for analysis.
2. Navigant ran the JEDI model for the new O&M jobs added in a given year and added those to the previously created O&M jobs. For each state, O&M labor, supply chain, and induced impacts were modeled with a single 100 MW project if new annual installations exceed 100 MW, and scaled based on the MW forecast for that year. If the annual MW forecast for each state is less than 100 MW, the actual MW forecast was modeled in JEDI.
3. National impacts modeled with "US" JEDI region. State-specific impacts modeled using the state region in JEDI.

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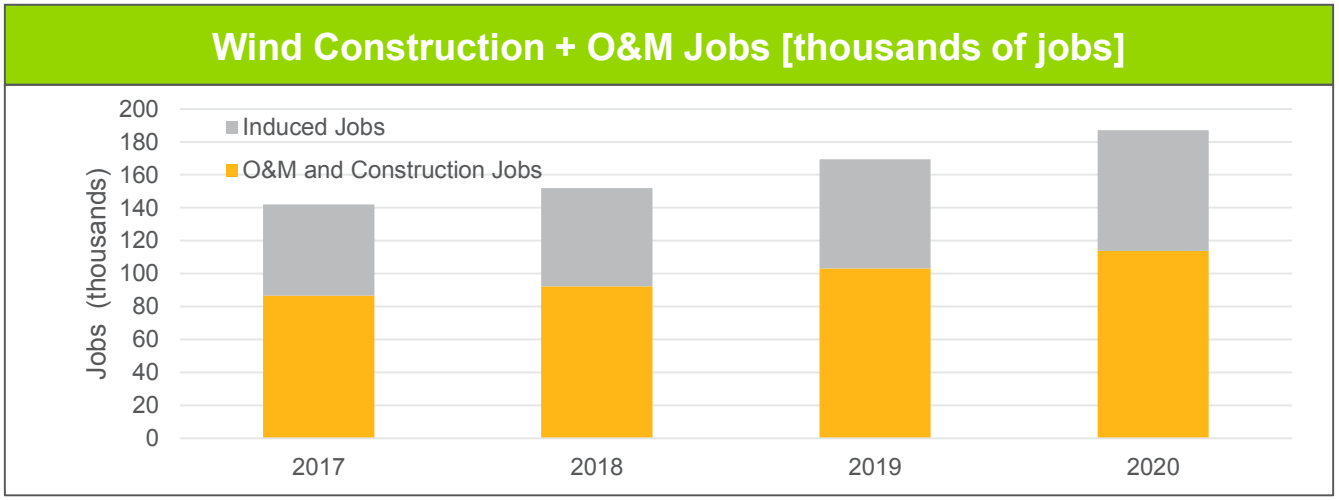
CONSTRUCTION AND OPERATION EMPLOYMENT

Total U.S. wind construction and O&M employment will peak at 187,000 jobs in 2020. O&M activities account for 110,000 ongoing jobs.



Notes:

- O&M and Construction includes direct and indirect jobs (to account for construction and O&M labor and supply chain employment).

[thousands of jobs]	2017	2018	2019	2020	2017-2020 (1)	Ongoing Annual
O&M and Construction Jobs (Direct + Indirect)	87	92	103	114	396	62
Induced Jobs	55	60	66	73	255	48
Total	142	152	169	187	650	110

1. 2017-2020 figures are in thousands of job-years

Source: Navigant, February 2017

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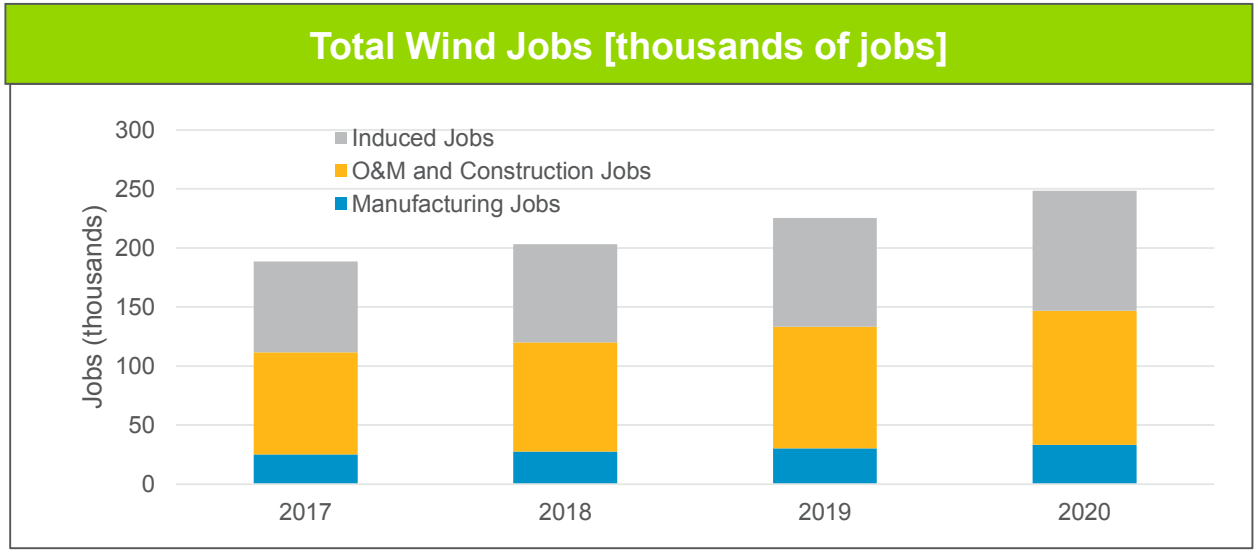
TOTAL WIND EMPLOYMENT

Total U.S. wind employment will peak at 248,000 jobs in 2020. From 2017 to 2020, there will be 865,000 wind-related job-years.



Notes:

- O&M and Construction includes direct and indirect jobs (to account for construction and O&M labor, and supply chain employment).
- Manufacturing includes direct jobs (parts assembly, etc.) and indirect supply chain jobs (steel manufacture, etc.)

Source: Navigant, February 2017

[thousands of jobs]	2017	2018	2019	2020	2017-2020 (1)
Manufacturing Jobs (Direct and Indirect)	25	28	30	33	116
O&M and Construction Jobs (Direct and Indirect)	87	92	103	114	396
Induced Jobs	77	83	92	102	354
Total	189	203	225	248	865

1. 2017-2020 figures are in thousands of job-years

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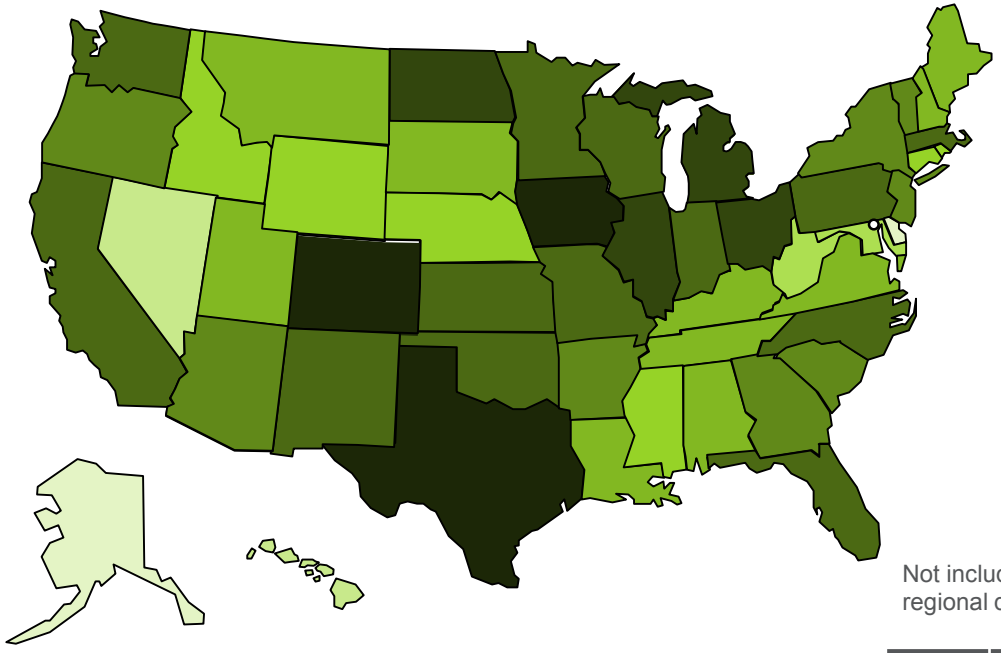
STATE-BY-STATE EMPLOYMENT

States with the highest total wind employment in 2017-2020 are TX, CO, and IA.

Cumulative (2017 to 2020) Wind Employment [Job-Years] [1,2]



Range			Unit	Color
Greater than		50,000	Job-Years	
25,000	to	50,000	Job-Years	
10,000	to	25,000	Job-Years	
5,000	to	10,000	Job-Years	
2,500	to	5,000	Job-Years	
1,000	to	2,500	Job-Years	
500	to	1,000	Job-Years	
100	to	500	Job-Years	
Less than		100	Job-Years	
None				

Not included: 55,700 annual non-regional direct and indirect jobs

Source: Navigant, February 2017

Rank	State	Jobs-years (2017-2020)
1	Texas	96,900
2	Colorado	78,400
3	Iowa	64,500

Notes:
1. Employment impacts include direct, indirect, and induced jobs.
2. Plot shows the projected 2017-2020 cumulative wind employment

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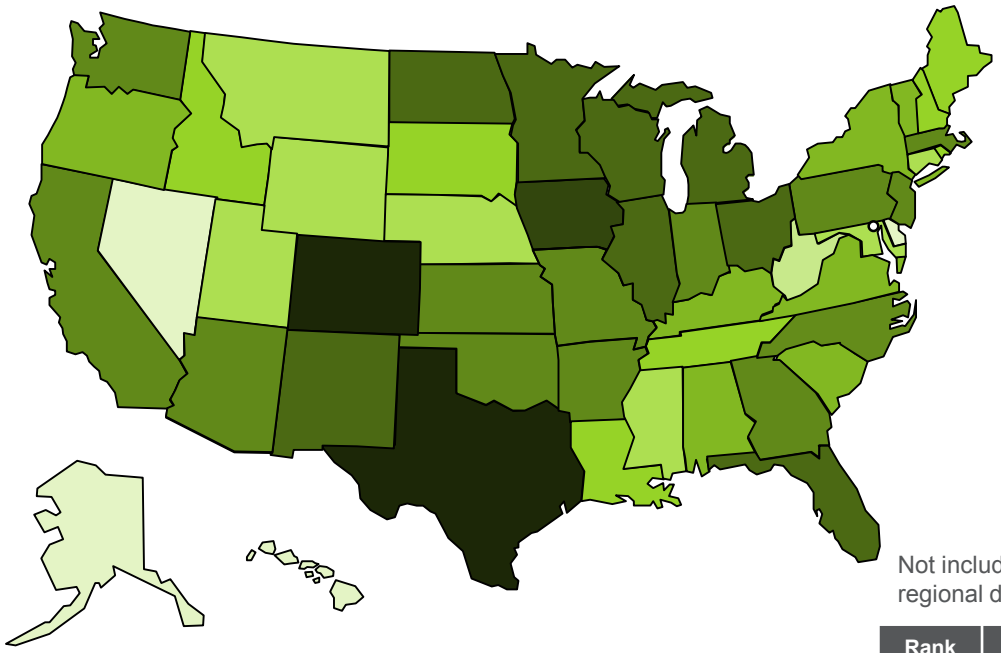
STATE-BY-STATE EMPLOYMENT

At the 2020 peak, Texas has the highest total wind employment with 31,500 jobs. Other states with high 2020 employment are CO and IA.

2020 Total Wind Employment [jobs][1]



Range			Unit	Color
Greater than		20,000	Jobs	
10,000	to	20,000	Jobs	
5,000	to	10,000	Jobs	
2,000	to	5,000	Jobs	
1,000	to	2,000	Jobs	
500	to	1,000	Jobs	
200	to	500	Jobs	
100	to	200	Jobs	
Less than		100	Jobs	
None				

Not included: 55,700 annual non-regional direct and indirect jobs

Source: Navigant, February 2017

Rank	State	Jobs (2020)
1	Texas	31,500
2	Colorado	22,900
3	Iowa	17,300

Notes:
1. Employment impacts include direct, indirect, and induced jobs.

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ECONOMIC IMPACT » OVERVIEW

Navigant analyzed the full economic impact of manufacturing, constructing, and operating wind power plants.

Economic Impact	=	**Expenditures for Manufactured Goods**	+	**Expenditures During Construction**	+	**Expenditures During Operation**	+	**Sales Tax Receipts**	+	**Federal and State Income Taxes**	+	**Property Taxes**
Definition		Money spent on turbines, blades, and towers that stays in the U.S.		Money spent during power plant development and construction		Money spent on employees and supplies during power plant operation, including land lease payments		Sales tax paid on goods and services during construction		Federal and state income taxes paid on power plant revenue		Local property taxes paid on power plant assets

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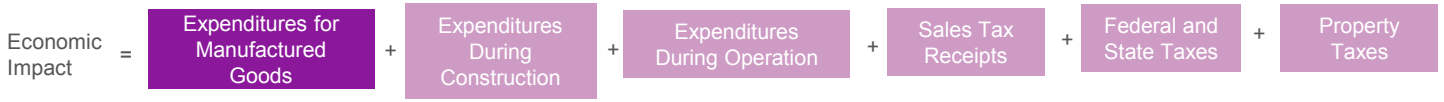
ECONOMIC IMPACT » MANUFACTURING

The amount of wind manufacturing done in the U.S., and the resulting revenue, varies by state.



» Navigant calculated the impact of money spent on wind manufacturing.

» Given that not all wind turbine components are installed in the U.S., Navigant assessed current and future domestic content under each scenario.

- Navigant used manufacturer interviews and its internal market knowledge to estimate domestic content.
- Manufacturers did not have a consensus on evolution of domestic content from 2017-2020.
- Navigant used an estimated industry-wide manufacturing domestic content average of 75%.
- Navigant assumed domestic content average would remain constant from 2017-2020.

» In each year of analysis, Navigant took the amount spent on each component and multiplied it by the domestic assumption to arrive at the impact.

» Navigant used investment multipliers from IMPLAN to calculate indirect & induced impacts.

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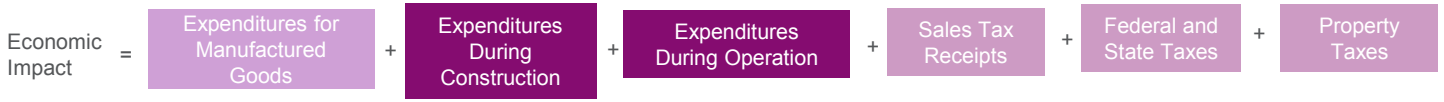
ECONOMIC IMPACT » CONSTRUCTION & OPERATION

Navigant used NREL's JEDI model to estimate expenditures during construction and operation.



» In addition to calculating employment impacts, the JEDI model tracks expenditures during construction and operation.

- Navigant used the same % local assumptions as for the employment analysis, JEDI defaults.
- JEDI uses IMPLAN multipliers to calculate the indirect and induced impact during construction and during the subsequent 25 years of operation.

» JEDI also captures the local benefits of land lease payments during operation.

- Navigant used the JEDI default of $3,000/MW-year for land lease payments. This value was also used in DOE's Wind Vision report.

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ECONOMIC IMPACT » TAXES

Navigant calculated the impact of sales tax paid during construction and income and property taxes during operation.

» During construction, plant developers pay sales tax on purchased equipment and goods.
- Navigant collected state level data on sales tax from the Federation of Tax Administrators (www.taxadmin.org)
- For each year of analysis, Navigant calculated the sales tax returns for installations in that year.

» During operation, plant owners pay federal and state taxes on the income from power sales.
- Navigant used Federation of Tax data on state corporate income tax rates and IRS data on federal corporate income tax rates.
- To calculate income,
  - Navigant used an estimated power sale price based upon the local Levelized Cost of Electricity, which is in turn influenced by local capacity factor and installed cost.
  - The power sale price was multiplied by annual generation to obtain revenue estimates.
  - Navigant assumed income was ~10% of revenue and applied the taxes to this income.

» During operation, plant owners pay state property taxes based on installed capacity.
- AWEA provided a list of state property taxes, taken from a Holland and Knight study and augmented by info from Polsinelli. For states with no specific data, Navigant used the U.S. average.

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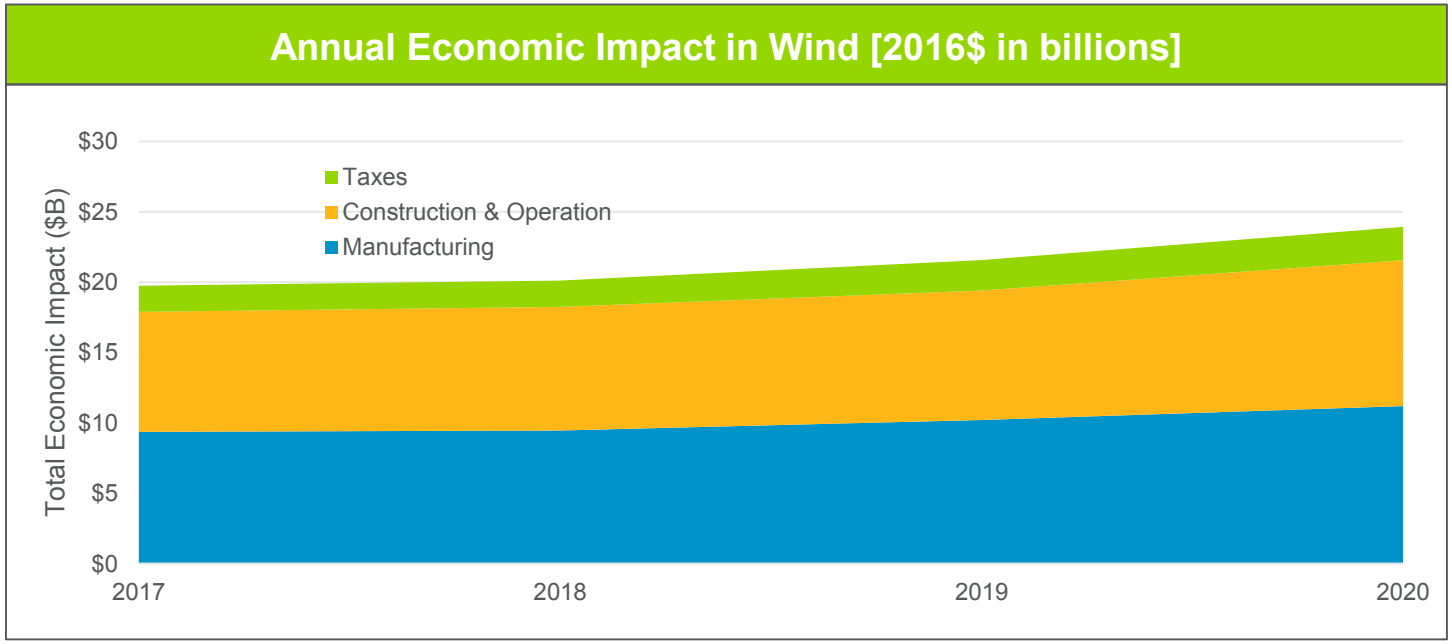
ECONOMIC IMPACT » RESULTS

Total annual economic impact of U.S. wind energy will reach $24 billion in 2020.



[2016$ in billions]	2017	2018	2019	2020	2017-2020
Manufacturing	9	9	10	11	40
Construction & Operation	9	9	9	10	37
Sales, Income & Property Taxes	2	2	2	2	8
Total Economic Impact	20	20	21	24	85

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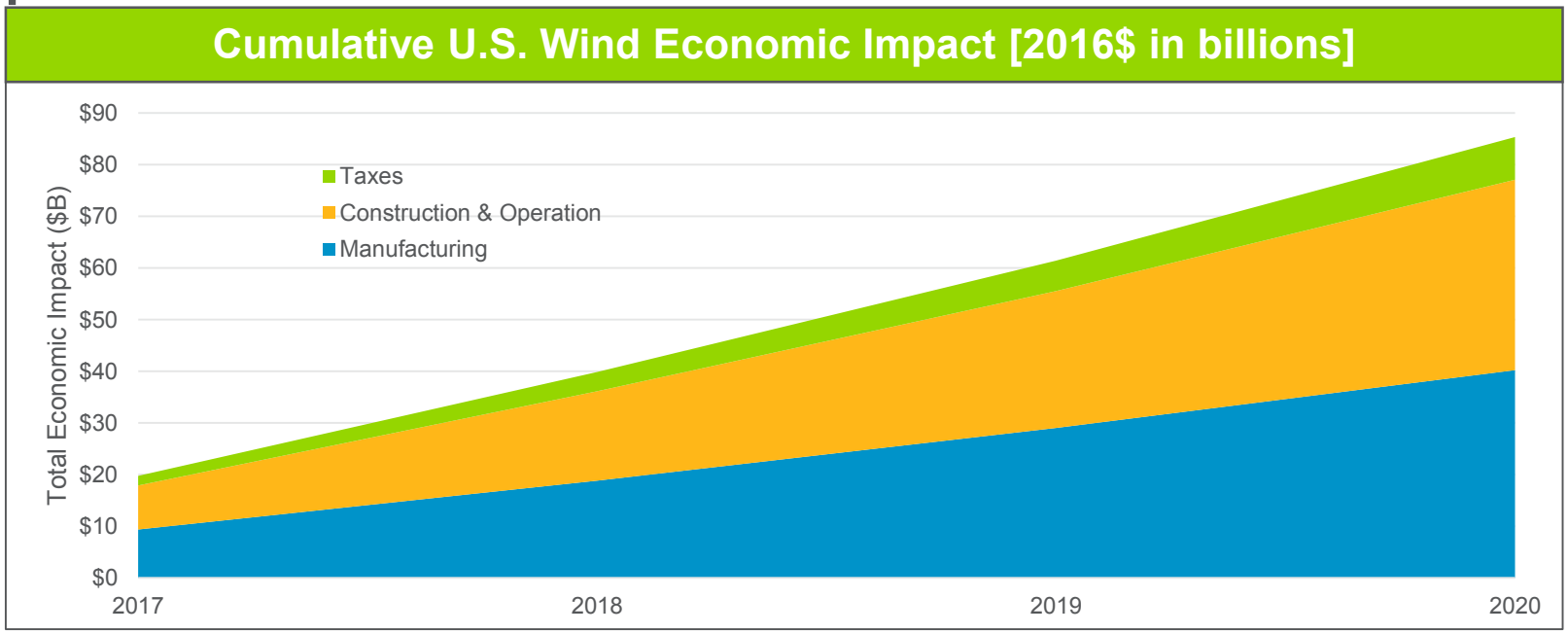
ECONOMIC IMPACT » RESULTS

U.S. cumulative wind project economic impact from 2017-2020 will equal $85 billion.



[2016$ in billions]	2017	2018	2019	2020
Manufacturing	9	19	29	40
Construction & Operation	9	17	27	37
Sales, Income, & Property Taxes	2	4	6	8
Total Economic Impact	20	40	61	85

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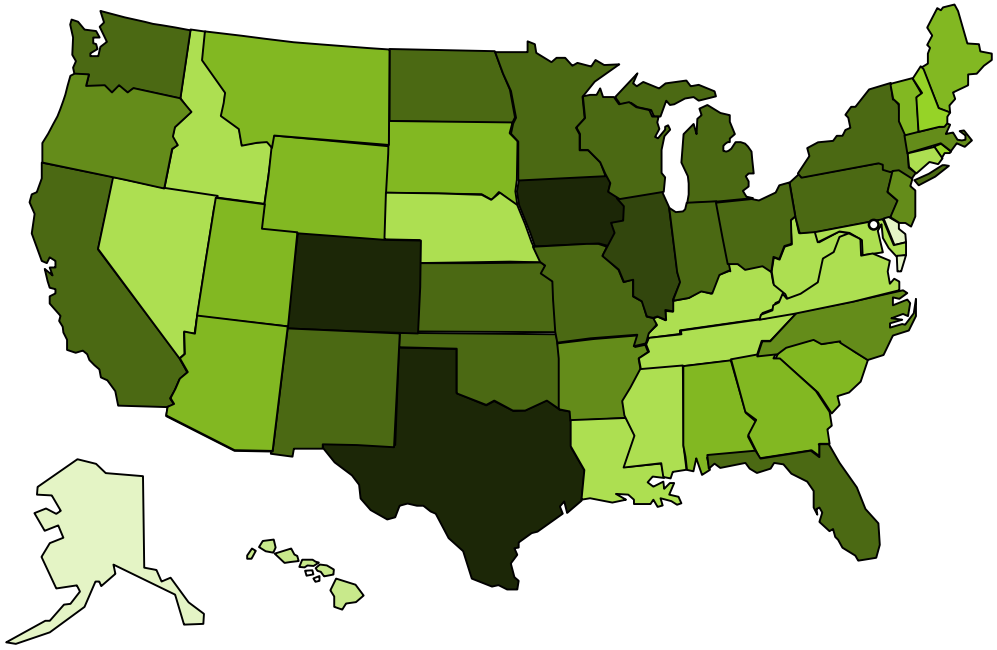
ECONOMIC IMPACT » RESULTS

States with the most total wind project economic impact from 2017-2020 are TX, IA, and CO.

Cumulative (2017 to 2020) State-by-State Wind Economic Impact [2016$ in millions]



Range			Unit	Color
Greater than		10,000	$MM	
5,000	to	10,000	$MM	
2,000	to	5,000	$MM	
1,000	to	2,000	$MM	
500	to	1,000	$MM	
200	to	500	$MM	
100	to	200	$MM	
50	to	100	$MM	
Less than		50	$MM	
None				

Rank	State	Investments ($MM) (2017-2020)
1	Texas	$16,000
2	Iowa	$9,300
3	Colorado	$8,400

Notes:
1. Economic impacts include direct, indirect, and induced impacts in millions of 2016$.
2. Plot shows the 2017-2020 cumulative economic impact of wind energy

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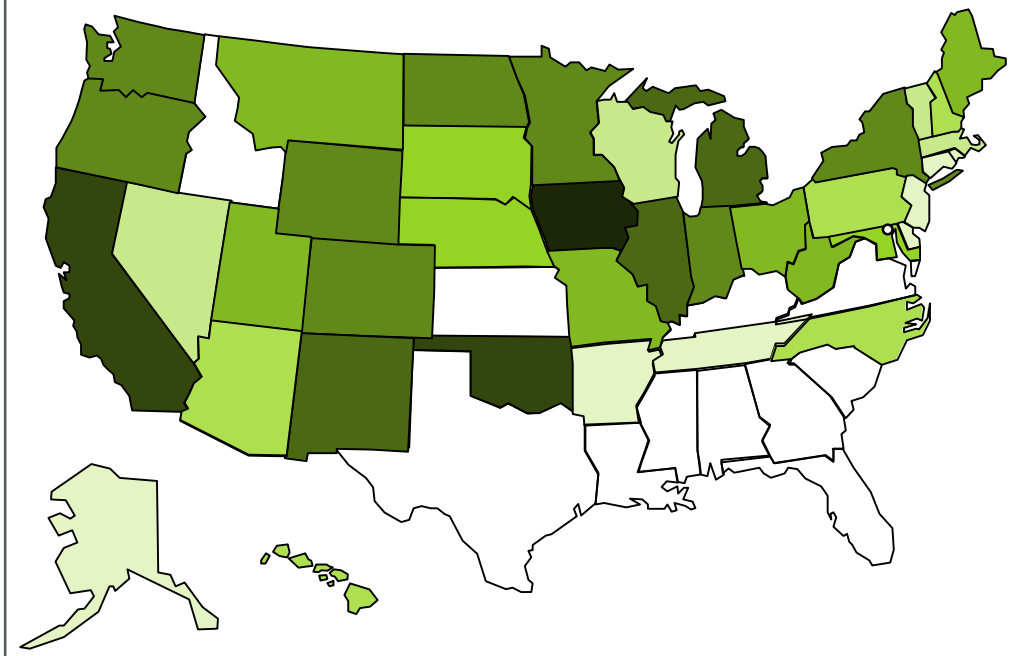
ECONOMIC IMPACT » RESULTS

States with the most total property tax paid by wind project owners in 2020 are IA, OK, and CA.

2020 State-by-State Property Tax [2016$ in millions]



Range			Unit	Color
Greater than		100	$MM	
50	to	100	$MM	
25	to	50	$MM	
10	to	25	$MM	
5	to	10	$MM	
2.5	to	5	$MM	
1.0	to	2.5	$MM	
0.5	to	1.0	$MM	
Less than		0.5	$MM	
None				

Rank	State	Property Tax ($MM) (2020)
1	Iowa	$120
2	Oklahoma	$80
3	California	$60

Notes:
1. Plot shows the 2020 property tax paid by owners of wind projects in millions of 2016$.

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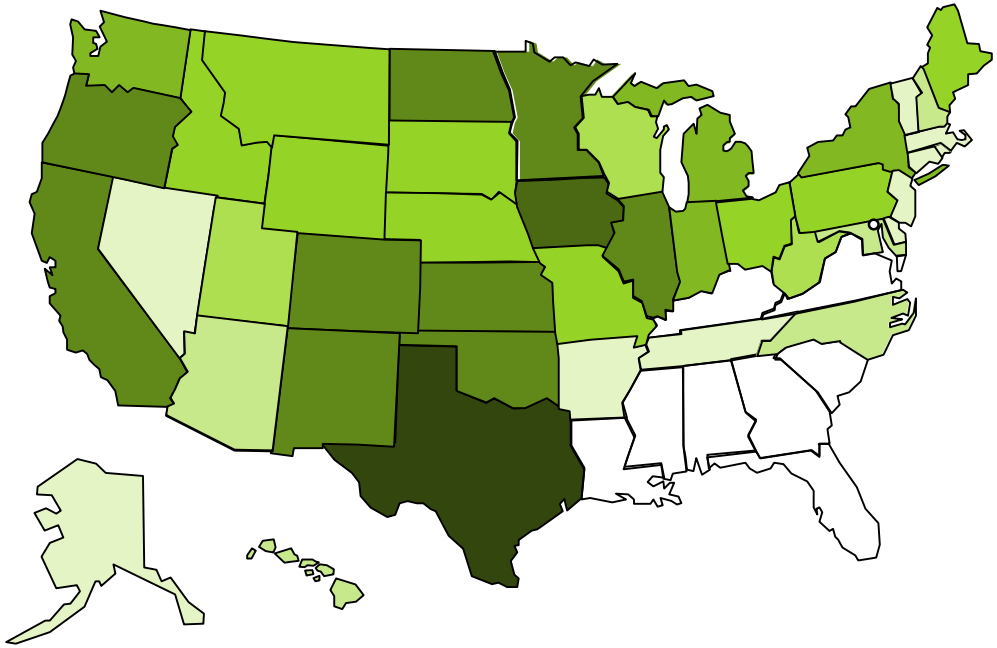
ECONOMIC IMPACT » RESULTS

States with the most total lease payments paid by wind project owners in 2020 are TX, IA, and OK.

2020 State-by-State Land Lease Payments [2016$ in millions]



Range			Unit	Color
Greater than		100	$MM	
50	to	100	$MM	
25	to	50	$MM	
10	to	25	$MM	
5	to	10	$MM	
2.5	to	5	$MM	
1.0	to	2.5	$MM	
0.5	to	1.0	$MM	
Less than		0.5	$MM	
None				

Rank	State	Lease Payments ($MM) (2020)
1	Texas	$97
2	Iowa	$43
3	Oklahoma	$22

Notes:
1. Plot shows the 2020 lease payments paid by owners of wind projects in millions of 2016$.

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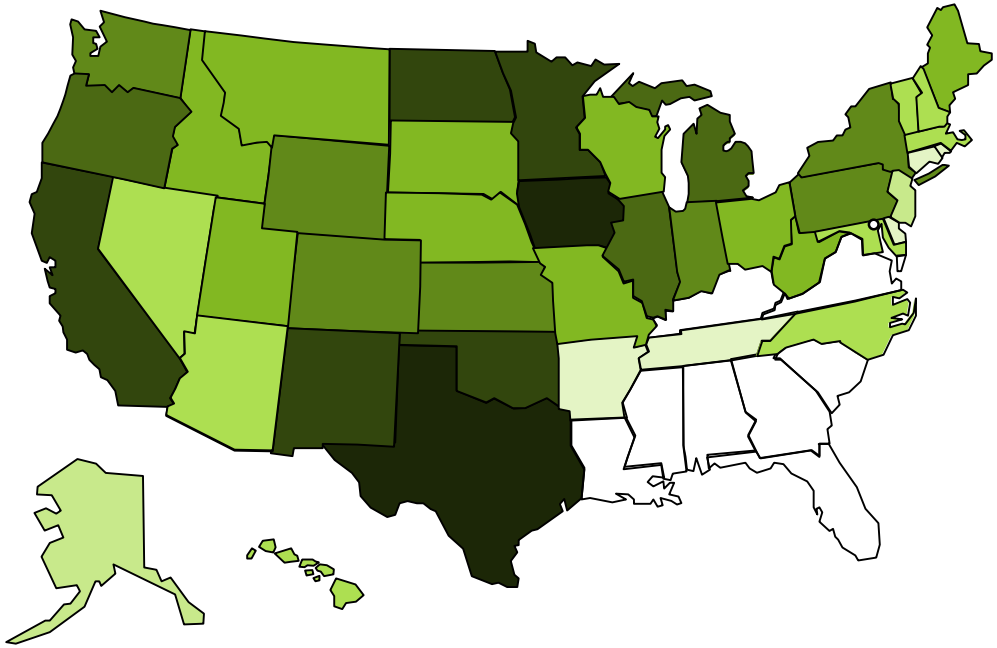
ECONOMIC IMPACT » RESULTS

States with the most total income, sales, and property tax paid by wind project owners in 2020 are TX, IA, and NM.

2020 State-by-State Income, Sales, and Property Tax [2016$ in millions]



Range			Unit	Color
Greater than		200	$MM	
100	to	200	$MM	
50	to	100	$MM	
20	to	50	$MM	
10	to	20	$MM	
5	to	10	$MM	
2	to	5	$MM	
1	to	2	$MM	
Less than		1	$MM	
None				

Rank	State	Taxes ($MM) (2020)
1	Texas	$590
2	Iowa	$370
3	New Mexico	$290

Notes:
1. Plot shows the 2020 income, sales, and property tax paid by owners of wind projects in millions of 2016$.

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CONCLUSIONS

The U.S. wind market will continue to grow through 2020, largely due to the extension of the Production Tax Credit.

Conclusions

Wind MW Forecast

» There will be 35 GW of new wind installations in 2017-2020.

» Annual U.S. wind installations will reach 10 GW in 2020.

Wind Employment and Economic Impact

» In 2017-2020, there will be 865,000 wind-related job-years of total employment.

- Manufacturing: 116,000 job-years of direct and indirect employment; 215,000 job-years of total employment.
- Construction and O&M: 396,000 job-years of direct and indirect employment; 650,000 job-years of total employment.

» In 2017-2020, there will be $85 billion in total U.S. wind-related economic impact.

- Manufacturing accounts for $40 billion
- Construction and O&M account for $37 billion
- Sales, Income and Property taxes account for $8 billion.

» TX, CO, & IA will experience highest employment. TX, IA, & CO will receive the most economic impact

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APPENDIX » DEFINITIONS

Key Definitions

FTE: Full time equivalent. Equals employment of one person for a year, or multiple people contributing enough hours to equal one person being employed for a year.

Job-Years: One job-year is equal to 1,960 hours (40 hours per week, 49 weeks per year). This can be one person employed for 1,960 hours, two people for 980 hours each, etc.

Direct Impacts: Represent the initial change in final demand for the industry sector in question. Direct impacts describe the changes in economic activity for sectors that first experience a change in demand because of a project, policy decision, or some other stimuli.

Indirect Impacts: Represent the response as supplying industries increase output in order to accommodate the initial change in final demand. These indirect beneficiaries will then spend money for supplies and services, which results in another round of indirect spending.

Induced Impacts: Generated by the spending of households who benefit from the additional wages and business income they earn through all of the direct and indirect activity. The increase in income, in effect, increases the purchasing power of households.

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APPENDIX » TYPES OF JOBS CREATED

Wind power manufacturing and installation requires a wide variety of skill sets and educational backgrounds.

Manufacturing Jobs

» Manufacturing
- Factory worker
- Technician
- Metal working
- Material handler
- Factory supervisor
- Quality assurance
- Manufacturing engineer
- Manufacturing manager

» Design
- Mechanical engineer
- Electrical engineer

» Administrative and support
- Director
- Purchasing agent
- Health and safety officer
- Accountant
- Administrative assistant
- Information technology professional

Installation Jobs

» Installation
- General contractor
- Shift supervisor
- Foreman
- Heavy construction

» Design
- Mechanical engineer
- Civil engineer
- Electrical engineer

» Administrative and support
- Health and safety officer
- Accountant
- Administrative assistant
- Information technology professional

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APPENDIX » JEDI RESULTS

JEDI outputs are categorized by Project/On-site impacts (Direct Jobs), Supply Chain impacts (Indirect Jobs), and Induced impacts

Construction – Examples of Jobs

- Project Development & On-site Labor
  - crane operators, road contractors, construction managers, electricians, tower erectors, excavation workers, backhoe operators, foundation workers, installation workers
  - civil and electrical engineers, attorneys, permitting specialists
- Local Revenue and Supply Chain Impacts
  - turbine manufacturers, turbine suppliers, gear manufacturers, blade manufacturers, blade suppliers, glass fiber manufacturers, tower manufacturers, tower suppliers, rebar manufacturers, gravel workers, banks, cement producers, accountants, heavy equipment rental companies, bookkeepers, etc.
- Induced Impacts
  - jobs and economic impacts that result from spending by workers involved in the first two categories

Operation – Example of Jobs

- Project Development & On-site Labor
  - clerical and bookkeeping support, site managers, field technicians, O&M workers, etc.
- Local Revenue and Supply Chain Impacts
  - turbine, blade and tower component suppliers for replacements, motor vehicle retailers, hardware and tool retailers, tool manufacturers, maintenance providers, metal fabricators, welders, material suppliers, agents at insurance companies, attendants at gas stations (for the vehicles used to operate and maintain the power plants), local government employees, local utilities, bookkeeping and accountants, banks, lawyers, etc.
- Induced Impacts
  - jobs and economic impacts that result from spending by workers involved in the first two categories

In the JEDI modeling, manufacturing jobs and economic impacts were not included in supply chain impacts; these impacts were calculated outside of JEDI.

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APPENDIX » JOBS BY STATE

Total Wind Jobs [thousands of jobs]					
State	'17	'18	'19	'20	'17-'20 (1)
Alabama	0.9	1.1	1.3	1.5	4.7
Alaska	0.0	0.0	0.0	0.0	0.1
Arizona	1.4	1.6	1.9	2.1	6.9
Arkansas	1.9	2.2	2.6	3.1	9.8
California	3.1	2.3	2.5	4.4	12.3
Colorado	14.8	20.8	19.9	22.9	78.4
Connecticut	0.2	0.3	0.3	0.4	1.2
Delaware	0.0	0.0	0.0	0.0	0.0
District of Columbia	0.0	0.0	0.0	0.0	0.0
Florida	3.5	4.0	4.8	5.6	18.0
Georgia	1.3	1.5	1.8	2.1	6.8
Hawaii	0.2	0.0	0.0	0.0	0.3
Idaho	0.4	0.4	0.5	0.5	1.9
Illinois	7.4	7.4	7.2	8.1	30.2
Indiana	2.5	4.0	2.7	3.0	12.2
Iowa	8.3	9.3	29.6	17.3	64.5
Kansas	4.3	2.5	2.8	3.1	12.8
Kentucky	0.7	0.8	1.0	1.1	3.6
Louisiana	0.6	0.6	0.8	0.9	2.8
Maine	0.7	0.6	0.6	0.7	2.5
Maryland	0.2	0.2	0.3	0.3	0.9
Massachusetts	2.7	3.1	3.7	4.3	13.7
Michigan	6.5	6.0	7.0	6.8	26.3
Minnesota	3.3	2.9	5.5	8.5	20.1
Mississippi	0.2	0.3	0.3	0.4	1.2

Total Wind Jobs [thousands of jobs]					
State	'17	'18	'19	'20	'17-'20 (1)
Missouri	3.2	2.6	3.0	3.5	12.4
Montana	0.3	2.4	0.3	0.3	3.3
Nebraska	0.3	0.3	0.3	0.3	1.1
Nevada	0.0	0.0	0.0	0.0	0.1
New Hampshire	0.6	1.0	0.8	0.9	3.2
New Jersey	1.9	2.5	2.6	3.0	10.0
New Mexico	1.7	3.2	2.4	6.8	14.2
New York	1.6	2.1	1.4	1.6	6.6
North Carolina	3.4	3.1	3.7	4.3	14.6
North Dakota	5.1	4.8	8.3	9.1	27.2
Ohio	6.9	6.2	7.1	8.2	28.4
Oklahoma	3.6	4.3	3.3	3.6	14.9
Oregon	1.5	1.4	2.2	1.8	6.9
Pennsylvania	3.1	3.6	4.2	4.8	15.7
Rhode Island	0.4	0.5	0.6	0.7	2.3
South Carolina	1.1	1.3	1.5	1.8	5.7
South Dakota	0.8	0.8	0.6	0.7	2.9
Tennessee	0.5	0.6	0.7	0.8	2.6
Texas	22.7	23.9	18.9	31.5	96.9
Utah	0.6	1.9	0.3	0.3	3.1
Vermont	1.3	1.4	1.5	1.7	5.9
Virginia	0.7	0.8	1.0	1.1	3.5
Washington	2.2	2.5	2.9	3.3	10.9
West Virginia	0.1	0.1	0.1	0.1	0.5
Wisconsin	4.2	3.8	4.5	5.2	17.8
Wyoming	0.3	0.5	0.3	0.3	1.3
Non-regional 2	56	56	56	56	222.3
Total	188.5	203.1	225.4	248.4	865.5

1. 2017-2020 figures are in thousands of job-years. 2. Non-regional jobs are U.S. domestic but not identified by state in JEDI.

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ENERGY

New report says wind energy could add thousands of jobs by 2020

03/29/17 3:10 PM *By Ben Nuelle*

KEYWORDS ELECTRICITY ENERGY IOWA JOBS WIND WIND-RELATED

WASHINGTON, March 29, 2017 - A new report released by Navigant Consulting says wind energy could create over 17,000 Iowa jobs and generate $9 billion in economic activity by 2020.

“Perhaps the most important impact wind has had on our state are the high-quality, good-paying jobs that are helping grow family incomes in Iowa,” Branstad said. “But wind has also helped us reduce our dependence on foreign oil—something that Iowa was almost exclusively reliant upon in the 1980’s when I was first governor.”

According to new analysis from Navigant, released Monday by the American Wind Energy Association, wind-related jobs can reach 11,500 direct and indirect jobs by 2020. When considering induced jobs this rises to 17,300 wind-related jobs. Iowa is projected to contain the third most wind-related jobs, trailing only Texas and Colorado.

“Iowa’s become a national leader in wind energy thanks to Gov. Branstad’s own leadership,” Iowa Wind Energy Association Vice President John Boorman said. “Iowans can continue to benefit from growing low-cost, reliable wind energy here in the Hawkeye State as Lt. Governor Reynolds follows in his footsteps.”

April 16, 2017

Darren Ash, CIO of USDA Farm Service Agency

This week’s guest on Open Mic is Darren Ash, Chief Information officer for the Farm Service Agency. As legislators prepare to write new farm policy, work is already underway at the USDA to receive, store, manage and share data to implement the new plan. The National Ag Imagery Program includes up to date aerial photography as well as digitizing over a half century of farm images to be used by

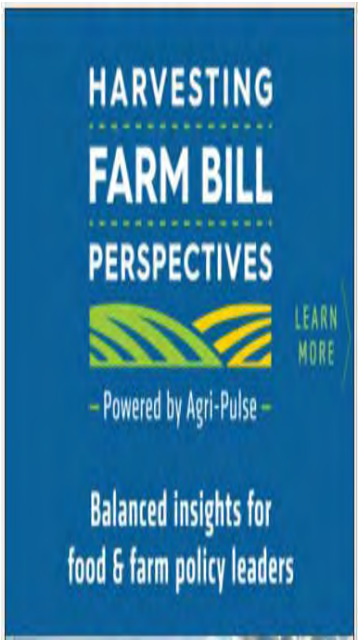
various federal agencies.

Reynolds added, “As Chair of the Iowa Energy Plan, I’ve seen and heard first-hand from existing and prospective companies how important it is to have clean, renewable and reliable sources of energy like wind. This report shows that by attracting businesses with sound policy, our economy has benefited from wind energy by creating jobs and attracting billions in private investment.”

The Navigant report says over the wind industry will contribute $9 billion in economic activity is in Iowa from 2017-2020. This includes investments in new wind projects, operational expenditures, land lease payments, and sales, income, and property tax payments. Only Texas will experience more economic activity from the U.S. wind industry.

Over the next four years, more than $370 million in income, sales, and property tax payments are expected to be made by Iowa wind projects.

According to the U.S Department of Energy, at over 36 percent, Iowa already leads the country in the percentage of electricity the state obtains from wind energy, and that can grow to 40 percent by 2020.



“Gov. Terry Branstad knows wind works for Iowa and it’s largely thanks to him that over 17,000 wind-related jobs in Iowa are possible in just a few years,” Tom Kiernan, CEO of American Wind Energy Association said. **“Wind does not provide just well-paying jobs either, many Iowans also know wind farms are the new ‘drought-resistant cash crop’ in Iowa, paying up to $20 million a year to Iowa farmers.** Wind is already responsible for more than 36 percent of Iowa’s electricity generation, and with recent project announcements, the state will push past 40 percent in the coming years. We’re going to work with elected officials in Iowa to make sure that happens.”

By growing wind, Iowa has already seen tremendous economic benefits including, $11.8 billion in private investment to the state’s economy, over 9,000 well-paying direct and indirect jobs, including manufacturing jobs at 11 wind-related manufacturing facilities in Iowa, and wind farm owners pay $20 million a year to Iowa farmers and other rural landowners.

Wind energy supplies 5.5 percent of U.S electricity today and is on track to supply 10 percent of U.S electricity by 2020. Nationally, Navigant Consulting projects with additional wind growth, will add 248,000 wind-related jobs by 2020.

Wind energy is important economic development tool

Jay Byers, Iowa View contributor Published 3:30 p.m. CT Dec. 29, 2016 | **Updated 1:27 p.m. CT Dec. 30, 2016**

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Attracting new private investment is never an easy task. But by encouraging renewable energy development long before most saw the value, Iowa has now positioned itself as a national leader. After the partisanship of the recent political campaign season, there is an even greater need for our state to highlight the bipartisan nature of this success.

In 1983, Iowa became the frst state to recognize the potential of wind energy by establishing a Renewable Portfolio Standard during Gov. Terry Branstad's frst tenure. A little over a decade later, Sen. Chuck Grassley became known as the "grandfather" of the federal wind energy Production Tax Credit for his role in securing the credit as part of the Energy Policy Act of 1992.Together, these forward-thinking policies have given our state a competitive advantage in producing wind energy and are driving economic growth throughout the state and region. Many Iowa communities, including the Greater Des Moines area, are reaping the rewards.

Iowa now generates more than one-third of its electricity from wind power, and the state's energy rates are the seventh lowest in the country — 22 percent below the national average. The correlation between Iowa's wind generation and its low energy rates can't be overlooked. Wind power is frequently the lowest cost source of electricity on the grid, and adding wind power has helped create a business-friendly environment in our state that has helped Greater Des Moines attract both new businesses and those looking to expand.

The affordability and stability of energy costs is an important factor for companies as they seek consistency for long-term planning. Wind energy, with largely fxed costs, has helped hedge Iowa companies against unpredictable market fuctuations af fecting other energy sources, and has contributed to central Iowa's national reputation as a great place to do business.

With some of the best wind resources in the country, we've still barely tapped our potential. Iowa ratepayers could save $12.6 billion over the next 25 years, with average annual savings in excess of $500 million, if the state were to double the currently planned and installed wind capacity, according to a recent report by the Wind Energy Foundation and the American Wind Energy Association. The average industrial consumer would, on net, save about $825,000 on electric bills and the average residential household would save about $3,200 over that period if their electricity needs were met by wind.

In 2015 alone, existing Iowa wind provided more than $500 million in gross benefts, or

$28 for each megawatt hour. Wind energy will likely be an even better investment over time as other fuels such as natural gas are expected to increase in price, according to projections from the U.S. Department of Energy.

The wind energy investments throughout the state also have created a ripple effect of other economic development opportunities. More than 6,000 Iowans are employed within the wind industry, including manufacturing, operations and maintenance, design and engineering professionals. In central Iowa, the city of Newton boasts two of the industry's largest manufacturers — TPI Composites and Trinity Structural Towers — truly showcasing the job creation potential of the wind industry.

Iowa communities beneft from more than $17 million in annual lease payments to landowners hosting wind turbines on their land, in addition to property taxes and other payments that help build schools and repair bridges and roads. Nationally, more than 80 percent of all wind farms are in Republican-held congressional districts, showcasing the opportunity for bipartisan support.

Wind energy also has accounted for at least $11.8 billion in capital investments in the state, and has been identifed as one of the reasons companies like Facebook choose to locate new facilities in Iowa.

Whether it's using wind energy to recruit new companies to the state or keeping costs low for consumers, Iowa wind energy is contributing to Greater Des Moines' strong growth and momentum, and benefttting the entire state. And with a record number of in-state wind projects now under development — including a wind farm that represents the largest economic development project in the state's history — it is more important than ever that the federal tax credits stay in place until their planned expiration date.

Iowa leaders have a unique opportunity to showcase the bipartisan, economic success story of our wind energy nationwide. We stand ready to help educate newly elected leaders around the country how strategic investments in wind energy infrastructure can lead to long-term, low-cost energy that's good for business and creates jobs.

Jay Byers is CEO of the Greater Des Moines Partnership.

Jay Byers, a storyteller with the Des Moines Storytellers Project, will tell a tale about Iowa Pride on Saturday, Aug. 20, at the State Fair. *(Photo: Special to the Register)*

AD CONTENT

Wind energy to add billions to Illinois economy

Eric Jome July 22, 2016

Filed Under: Center for Renewable Energy, College of Applied Science and Technology, Media Relations, University

309 50

Illinois' 25 largest wind farms have supported 20,173 jobs during construction and will add $6.4 billion to local economies over the 25-year life of the projects.

That is one of the findings of a study on the economic impact of wind energy released by Illinois State University's Center for Renewable Energy. Center Director David Loomis announced the findings at the Illinois Renewable Energy Conference in Normal on July 21.

"Wind energy has played an increasingly important part in the state's energy mix resulting in numerous economic development benefits," Loomis said. "Decision-makers need to be well-informed about these benefits so that they consider all of the factors when deciding on future wind projects."

The Center's report adds that the 25 largest wind farms in Illinois support about 869 permanent jobs with 226 direct jobs in rural areas in Illinois. The wind farms generate $30.4 million in annual property taxes for local communities and $13.86 million in extra income for landowners who lease their land to developers.

According to the U.S. Department of Energy, Illinois could become the second largest wind state in the country behind Texas by 2050. Illinois is currently fifth, ranked behind Texas, Iowa, California, and Oklahoma. In order to become the second largest wind state, Illinois would need to add about 10 times its current wind capacity, which could result in approximately 10 times the number of jobs supported.

McLean County leads the state with 546 megawatts, or 15.1 percent of the state's wind capacity. LaSalle and Lee counties are next with 9.8 and 9.7 percent of the state's capacity, respectively.

Illinois built two new wind farms in 2015 after two years of not building any. Several new wind farms were permitted in 2015 and could start construction in 2016.

"State energy policy will be key to Illinois' wind energy future," said Loomis. "Current legislative proposals could fix the state's renewable portfolio standard and increase the percentage of our electricity coming from renewable energy."

WIND ENERGY AND HEALTH

APEX CLEAN ENERGY

WIND ENERGY AND HEALTH

More than 52,000 wind turbines are in operation in the United States today, safely generating electricity for our nation. Wind energy is one of the healthiest forms of energy generation in the world because it releases no greenhouse gases, soot, or carbon into the atmosphere; it also does not consume valuable freshwater or produce water pollution. Apex wind projects are built in full compliance with local, state, and federal safety regulations to protect the health and welfare of landowners, maintenance teams, and others.

Key Findings from Health Impact Studies

Government- and university-sponsored studies around the world have repeatedly confirmed that modern, properly sited wind turbines pose no threat to public health. A growing number of studies reviewed by independent experts on wind energy and health have reached the same conclusion.

The World Health Organization, which classifies diseases, does not recognize wind turbine syndrome, nor does any other medical institution.

Wind Turbine Sound

The sound of wind turbine blades passing through the air is often described as a "whoosh." If properly constructed at approved setback distances, the sound does not result in any health concerns. Scientific evidence confirms that this sound is not detrimental and that any low-frequency or infrasound waves produced are not harmful to those nearby.*

Noise from wind turbines, including low-frequency noise and infrasound, is similar to noise from many other natural and human-made sources. There is no reliable or consistent evidence that proximity to wind farms directly causes health effects.†

"... infrasound emitted by wind turbines is minimal and of no consequence ... Further, numerous reports have concluded that there is no evidence of health effects arising from infrasound or low frequency noise generated by wind turbines."‡

Shadow Flicker

This term refers to the shadows cast by wind turbine blades as they rotate in front of the sun. By positioning wind turbines at a carefully calculated angle and distance from dwellings, Apex ensures that most homes in a project experience no shadowing at all. For those that do, shadowing should occur for no more than a few minutes per day, on average. Shadowing does not occur on cloudy or foggy days.

While some have claimed that shadow flicker can create risk of seizures in photosensitive individuals, scientific evidence suggests that shadow flicker does not pose a risk of inducing seizures in people with photosensitive epilepsy.‡

The risk of ice striking a home 984 feet from a turbine is extremely low—researchers estimate that if it happens at all, it is only likely to occur once every 625 years.

*Journal of Occupational and Environmental Medicine, "Wind Turbines and Health-MIT," November 2014.
†Australian Government, National Health and Medical Research Council, "Evidence on Wind Farms and Human Health," February 2015.
‡Frontiers in Public Health, "Wind Turbines and Human Health," June 2014.

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APEX CLEAN ENERGY

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Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005

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HIGHLIGHTS

- Ozone and PM impacts of the major combustion sectors in the U.S. are modeled.
- Early deaths attributable to each sector are estimated.
- ~200,000 early deaths occur in the U.S. each year due to U.S. combustion emissions.
- The leading causes are road transportation and power generation.

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ABSTRACT

Combustion emissions adversely impact air quality and human health. A multiscale air quality model is applied to assess the health impacts of major emissions sectors in United States. Emissions are classified according to six different sources: electric power generation, industry, commercial and residential sources, road transportation, marine transportation and rail transportation. Epidemiological evidence is used to relate long-term population exposure to sector-induced changes in the concentrations of $PM_{2.5}$ and ozone to incidences of premature death. Total combustion emissions in the U.S. account for about 200,000 (90% CI: 90,000–362,000) premature deaths per year in the U.S. due to changes in $PM_{2.5}$ concentrations, and about 10,000 (90% CI: −1000 to 21,000) deaths due to changes in ozone concentrations. The largest contributors for both pollutant-related mortalities are road transportation, causing ~53,000 (90% CI: 24,000–95,000) $PM_{2.5}$-related deaths and ~5000 (90% CI: −900 to 11,000) ozone-related early deaths per year, and power generation, causing ~52,000 (90% CI: 23,000–94,000) $PM_{2.5}$-related and ~2000 (90% CI: −300 to 4000) ozone-related premature mortalities per year. Industrial emissions contribute to ~41,000 (90% CI: 18,000–74,000) early deaths from $PM_{2.5}$ and ~2000 (90% CI: 0 −4000) early deaths from ozone. The results are indicative of the extent to which policy measures could be undertaken in order to mitigate the impact of specific emissions from different sectors — in particular black carbon emissions from road transportation and sulfur dioxide emissions from power generation.

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1. Introduction

Air pollution adversely affects human health (U.S. EPA, 2011a; WHO, 2006; COMEAP, 2010). The emission of pollutants into the atmosphere is an inherent by-product of combustion processes. Recent research has found that ambient concentrations of fine particulate matter (smaller than 2.5 μm in aerodynamic diameter, $PM_{2.5}$) (Dockery et al., 1993; Pope et al., 2002; WHO, 2006) and ozone (Bell et al., 2004; Jerrett et al., 2009; WHO, 2008a) are associated with the incidence of premature mortality and morbidity outcomes. Although other anthropogenic air pollutants are recognized as causes of adverse health impacts, ground level $PM_{2.5}$ and ozone exposure is currently considered the most significant known cause of early deaths related to poor outdoor air quality (U.S. EPA, 2011a). The U.S. Environmental Protection Agency estimated that in 2010 there were ~160,000 premature deaths in the U.S. due to $PM_{2.5}$ exposure and ~4300 deaths related to ozone exposure. Fann et al. (2012) estimated between 130,000 and 340,000 $PM_{2.5}$-related early deaths in 2005, and between 4700 and 19,000 ozone-related early deaths.

In the U.S., air pollution is regulated by the Clean Air Act and its amendments (1970 through 1990), which enables the EPA to set

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national air quality standards for six criteria air pollutants including $PM_{2.5}$ and ozone (U.S. EPA, 2011a). The Environmental Protection Agency estimated that in 2012 about 74 million people in the U.S. are exposed to levels of $PM_{2.5}$ higher than the limit standard and that more than 131 million live in regions not compliant with maximum allowable ozone levels (U.S. EPA, 2012b). The EPA computed the costs for the implementation of the 1990 Clean Air Act to be about 65 billion dollars, with a potential benefit reaching 2 trillion dollars from 1990 to 2020, potentially avoiding ~230,000 premature deaths in 2020 (U.S. EPA, 2011a). Although the CAA90 policy-implementation costs are distributed among different source categories, the attribution of air quality-related premature mortalities to different sectors has not been quantified in the peer-reviewed literature. An assessment of the early deaths attributable to different sources would create the potential to drive specific policies with the aim of maximizing the health benefits related to emission reductions from a certain economic activity. In the U.S., anthropogenic combustion emissions represent the predominant source of ground level $PM_{2.5}$ and ozone concentrations (U.S. EPA, 2011a).

In the first part of the present study we evaluate premature deaths attributable to U.S. combustion emissions represented by the following sectors: electric power generation, industry, commercial/residential activities, road transport, marine transport and rail transport. The contribution of $PM_{2.5}$ and ozone-related mortalities is quantified to inform policy makers about opportunities to diversify regulations by taking into account the health impact caused by different types of human activities. The second part of the study (Part II) will focus on assessing future-year combustion emissions impacts from different sectors and on future possible mitigation strategies.

2. Data and methodology

The health impacts of combustion emissions from different sectors are evaluated through the derivation of a temporally, spatially and chemically resolved emissions inventory in the contiguous United States (CONUS), and parts of Canada and Mexico for the reference year 2005. Meteorology and air quality models are used to relate emissions to pollutant concentrations. A baseline simulation, including all emission sources, is performed to assess the model capability to predict meteorological fields, particulate matter and ozone concentrations. Sector emission scenarios are developed wherein combustion emissions from each of the six emission sectors defined above are removed in turn from the baseline inventory; differences in particulate matter and ozone concentrations between the baseline and sector scenario simulations are attributed to the contribution of that specific sector. Population exposure to sector-attributable $PM_{2.5}$ and ozone concentrations are used with concentration-response functions (CRFs) to estimate premature mortality impacts of each sector.

The calculated mortalities can be seen as potentially avoidable deaths in the reference year 2005 related to the instantaneous removal of combustion emissions from each specific sector. An extensive discussion about the use of number of premature deaths per year as a metric for anthropogenic health impact assessments is given by the UK Committee on the Medical Effects of Air Pollutants (COMEAP, 2010). The approach adopted in this study follows the methodology for the evaluation of "current" health burdens from air pollution described by COMEAP (2010). The remainder of this section details each of the steps previously described.

2.1. Meteorological modeling

The modeling domain is centered about the CONUS, including parts of Canada and Mexico. The horizontal resolution is 36 km (112 rows by 148 columns), with 34 sigma-pressure vertical layers. Meteorological fields for the year 2005 are derived using the Weather Research and Forecasting Model (WRF version 3.3.1; Skamarock et al., 2008), driven by four-dimensional data assimilation from the six-hourly NCEP Final Analyses (FNL) data at $1^\circ \times 1^\circ$ resolution. Meteorological simulations are validated against direct hourly temperature and wind observations from 1672 and 1619 stations, respectively. Observations are collected by the Meteorological Assimilation Data Ingest System (MADIS, 2010), developed by the National Oceanic and Atmospheric Administration (NOAA).

2.2. Emissions

Baseline emissions in the U.S., Canada and Mexico are derived from the 2005 EPA National Emissions Inventory (NEI; U.S. EPA, 2008a). This represents the most up to date emissions inventory at the time of this study. NEI 2005 emissions are compiled using data from numerous state and local agencies. The Sparse Matrix Operator Kernel Emissions program version 2.6 (SMOKE, 2010) is used to prepare emissions for the air quality model. SMOKE applies chemical speciation profiles (in case of PM, NO_x and Volatile Organic Compounds), temporal profiles and spatial surrogates for allocation of emissions into model grid-cells. The spatial surrogates are compiled by the EPA (SMOKE, 2010) to allocate area and line sources (which are often specified as county totals) to the CMAQ model grid cells. The emissions are distributed using area-weighting, and the emission allocation is done based on source classification codes (SCCs).

Pre-processed WRF meteorological fields are used to treat emissions from mobile sources for which emissions factors are significantly influenced by local temperature and relative humidity (Ashok, 2011) as well as to compute the plume rise of point-source emission sources and vertically allocate them into the model layers. Emissions scenarios are developed for six source categories ("sectors"): (a) electric power generation, (b) industry, (c) commercial/residential, (d) road transportation, (e) marine transportation, (f) rail transportation. Sectors are defined with differences relative to EPA source categories (U.S. EPA, 2008b) including that commercial and residential sources are merged together and transportation is divided into three separate sectors (discussed later). The division of the transportation sector is performed in order to capture contributions from different modes of transportation and assess modal emission mitigation strategies in future years in the second part of the study.

Sector emissions are taken out from each scenario by removing, in turn, the sources associated to the specific sector from the baseline NEI dataset. Aviation emissions are included in the baseline case, but aviation is not explicitly considered as a sector here since the premature mortalities related to this specific sector have been assessed in Yim et al. (2013). Sector-attributable emissions are considered only in the CONUS together with the U.S. maritime exclusive economic zone (200 nmi off the coastline, plus maritime boundaries with adjacent/opposite countries). Emissions from Canada and Mexico are kept in all the simulations at their original baseline values. We thus focus our investigation on the health impacts on U.S. population from sources located within the U.S. territory. The CONUS and maritime boundary specifications are taken from the National Atlas of the United States of America (2012) and from the Office of Coast Survey (OCS) of the NOAA (1998).

Totals for primary particulate matter, NO_x and SO_2 emissions for the reference year 2005 from each of the sectors are given in Table 1. Combustion emissions from the sectors considered account for 82% of the NO_x anthropogenic emissions in the continental U.S., and 98% of the sulfur dioxide emissions. Emissions from fugitive dust, agricultural activities, aviation and other non-combustion sources are not considered in the sector specifications.

Table 1
$PM_{2.5}$ (primary), NO_x and SO_2 emissions totals and percentages with respect to the baseline scenario (NEI, 2005 dataset, including all sources). Emissions are expressed in Tg $year^{-1}$ for each sector considered in the study (data for 2005).

Sector	$PM_{2.5}$		NO_x		SO_x	
	Total	%	Total	%	Total	%
Electric power generation	0.46	11.7%	3.42	16.1%	9.46	70.4%
Industry	0.57	14.5%	2.75	13.0%	2.55	19.0%
Commercial/residential	0.69	17.6%	0.76	3.6%	0.49	3.6%
Road transportation	0.27	6.9%	8.17	38.5%	0.16	1.2%
Marine transportation	0.07	1.8%	1.30	6.1%	0.45	3.4%
Rail transportation	0.03	0.8%	1.01	4.8%	0.07	0.5%
Other	1.84	46.8%	3.81	18.0%	0.25	1.9%
Total	3.93	100.0%	21.22	100.0%	13.43	100.0%

It is possible to relate the totals found from the 2005 NEI to more recent estimates by using yearly total emissions trends for air pollutants in the U.S. (U.S. EPA, 2012a). The trends estimated by EPA indicate that with respect to 2005, in 2012 SO_2 emissions would be ~60% lower, NO_x emissions ~40% lower, and VOC emissions ~15% lower, while $PM_{2.5}$ and ammonia emissions are expected to increase by ~14% and ~5% respectively. We note that these figures are preliminary estimates and, particularly for SO_2 and NO_x, may be significantly revised.

2.3. Air quality modeling

Air quality simulations for the year 2005 are performed using the CMAQ (version 4.7.1) regional chemistry-transport model (Byun and Schere, 2006) at a spatial resolution of 36 km × 36 km. A two-week spin-up time is used to mitigate the influence of initial conditions. The initial and boundary conditions for the CMAQ simulations are provided by Barrett et al. (2012). Simulated $PM_{2.5}$ baseline concentrations are validated against 24-h averaged observations from 543 stations collected by the EPA Speciation Trends Network (STN). Ozone baseline concentrations are validated against hourly data from 538 stations from the U.S. EPA Air Quality System (AQS) (U.S. EPA, 2011b).

2.4. Health impacts

Epidemiological studies have quantified the relationship between adverse health effects and long-term exposure to $PM_{2.5}$ (U.S. EPA, 2011a; Lewtas, 2007; Krewski et al., 2009; Laden et al., 2006) and ozone (Bell et al., 2004; Jerrett et al., 2009). The quantitative association between premature mortality and ground-level concentrations of $PM_{2.5}$ and ozone is generally assessed through the derivation of relative risk (RR) factors and concentration-response functions (CRFs). An expert elicitation by the U.S. EPA reports a decrease of 1% (range 0.4%–1.8%) in annual all-cause deaths for a 1 μg m^{-3} decrease in the annual average $PM_{2.5}$ exposure in the United States (U.S. EPA, 2011a). Similar results are reported for Europe (Cooke et al., 2007). Jerrett et al. (2009) associated long-term ozone exposure with the risk of death from respiratory causes. In that study, the relative risk of early death from respiratory diseases as a consequence of an increase in ozone concentration of 10 ppb is estimated as 1.040 (95% confidence interval, 1.010–1.067).

$PM_{2.5}$ and ozone account for the majority of monetary losses related to the health impacts of air pollution (Ratliff et al., 2009), and as such long-term exposure to $PM_{2.5}$ and ozone form the focus of the present study. Premature deaths in the U.S. related to sector-attributable $PM_{2.5}$ are estimated using a linear CRF based on EPA assessments (U.S. EPA, 2011a) and described further in Barrett et al. (2012). The CRF associates long-term exposure to $PM_{2.5}$ with premature deaths from cardiopulmonary causes and lung cancer. For long-term exposure to ozone, a log-linear CRF derived from the results of Jerrett et al. (2009) is adopted, consistent with previous ozone health impact assessments in the U.S. (U.S. EPA, 2011a; Fann et al., 2012). The CRF evaluates the number of premature deaths Δy corresponding to a change in ozone concentration ΔO_3 (Abt Associates Inc. and U.S. EPA, 2012). Specifically,

$$\Delta y = y_0 \cdot \left(1 - \frac{1}{\exp(\beta \cdot \Delta O_3)}\right) \quad (1)$$

where y_0 is the baseline incidence rate of the health effect (death from respiratory diseases). The change in ozone concentration ΔO_3, specified in ppb, represents a change in the daily maximum ozone concentration averaged during the ozone season (April 1 – September 30), as described in Jerrett et al. (2009). The coefficient β takes on specific values for urban areas as well as region-specific values for rural areas based on the following geographical regions of the U.S.: Northeast, Industrial Midwest, Southeast, Upper Midwest, Northwest, Southwest, Southern California, as defined by the EPA (Krewski et al., 2000). Nominal values of β and standard error estimates used for uncertainty quantification are provided by the EPA (Abt Associates Inc. and U.S. EPA, 2012). For both $PM_{2.5}$ and ozone, mortalities are evaluated as single sector contributions for adults over 30 years old. Baseline incidences for pollutant-related mortalities (cardiopulmonary diseases and lung cancer for the $PM_{2.5}$ CRF, respiratory diseases for the ozone CRF) are taken from the WHO Global Burden of Disease (WHO, 2008b). Population density is retrieved from the Gridded Population of the World database (GPWv3, 2004).

2.5. Uncertainty assessment

The uncertainties inherent in the premature mortality calculations, including uncertainties from the CRF parameters as well as the air quality modeling, are quantified in this study. For $PM_{2.5}$ – related mortality calculations, the uncertainty in the CRF is accounted for with a triangular probability distribution of multiplicative factors with (low, nominal, high) values of (0.3, 1, 1.7) (U.S. EPA, 2006). The low, nominal and high values correspond to the vertices of the triangular distribution function. The distribution of CMAQ model normalized mean biases is used to account for the uncertainty in predicting PM concentrations, and it is modeled as a normal distribution of mean 7.55% and standard deviation of 28.1%. The minimum (−67.2%) and maximum (108.1%) normalized mean biases are adopted as limiting values to trim the tails of the normal distribution. The reciprocal of the biases distribution are used as multiplicative factors to correct CMAQ model predictions in the uncertainty calculations.

We note that the uncertainty related to different toxicities among $PM_{2.5}$ species as well as a ~10% probability of no causal link between $PM_{2.5}$ exposure and premature mortality (Roman et al., 2008) have not been accounted for quantitatively in this study. The assumption of equal toxicities is consistent with U.S. EPA expert elicitation studies (U.S. EPA, 2004), but represents an unquantified uncertainty (Levy et al., 2009). A similar approach is applied for the uncertainty assessment of ozone-related premature mortalities. For the ozone CRF shown in Equation (1) we consider a triangular probability distribution of multipliers with (low, nominal, high) values of ($\beta - 1.96\,\sigma_\beta$, β, $\beta + 1.96\,\sigma_\beta$), as tabulated in Abt Associates Inc. and U.S. EPA, 2012. The values σ_β of correspond to the standard errors for the health impact estimates performed by the CRF in different regions of the U.S. (Abt Associates Inc. and U.S. EPA, 2012). The β coefficients and their corresponding standard errors vary between each of the seven geographical regions of the U.S.

Table 2
Statistical model evaluation of WRF (wind speed and temperature) and CMAQ ($PM_{2.5}$ and ozone) against observations. Wind speed and temperature are evaluated on an hourly basis, $PM_{2.5}$ on a 24-h average, and ozone is evaluated as daily maximum values recorded during the ozone season (Apr–Sept). The units for each quantity are indicated in the table.

	Wind [m s^{-1}]	T [°C]	$PM_{2.5}$ [μg m^{-3}]	Ozone [ppb]
Model Mean	3.58	12.93	13.85	55.01
Model SD	2.14	11.76	9.39	15.74
Observed Mean	3.32	12.88	12.98	56.74
Observed SD	2.46	11.89	8.49	17.88
Index of Agreement	0.82	0.98	0.69	0.74
Correlation	0.68	0.97	0.49	0.57
Annual Mean Bias (%)	8.02	0.39	6.77	−3.04
Root-mean-square error	1.88	2.90	9.13	15.87
Mean Bias	0.22	0.05	0.88	−1.72
Mean Normalized Bias (%)	10.17	1.25	28.60	2.62
Normalized Mean Bias (%)	8.02	0.39	6.77	−3.04
Mean Fractional Bias (%)	30.24	10.42	1.90	−1.96
Mean Error	1.45	2.17	6.53	11.62
Normalized Mean Gross Error (%)	43.67	16.86	50.33	20.47
Mean Normalized Gross Error (%)	42.47	12.02	63.01	22.37
Mean Fractional Error (%)	65.47	−8.92	49.46	21.10
Data Availability (%)	74.74	76.94	73.73	98.12

described in Section 2.4. As such, the ozone CRF uncertainty bounds are computed individually for each of the regions. Region-specific uncertainty for the CMAQ ozone predictions is calculated using a normal distribution of normalized mean biases. Mean value, standard deviation and limits of the distributions are computed for each region following the same approach as for the $PM_{2.5}$-related model uncertainty evaluation.

3. Results

3.1. Model evaluation

Meteorological and air quality simulations are validated against observations using a set of statistical metrics recommended by the EPA (U.S. EPA, 2005). The definitions for each of the metrics can be found in Yim and Barrett (2012): in particular, an index of agreement (IA) of 1 indicates perfect agreement between the model and the available observations.

Overall the simulated meteorology and air quality statistics, shown in Table 2, are within the range or close to recent studies adopted for similar applications (Yim and Barrett, 2012; Gilliam and Pleim, 2010). Simulated wind speed (measured in m s^{-1}) exhibits an index of agreement of 0.82 and a normalized mean bias around 8% with respect to the available observations. Modeled temperature (measured in °C) shows an IA of 0.98 and a positive bias of 0.39%. The 24-h averaged fine particulate matter (in μg m^{-3}) computed by CMAQ has an index of agreement of 0.69. For ozone, daily maximum values (in ppb) during the ozone season (Apr–Sept) are computed, showing an index of agreement of 0.74. The model estimates the concentrations of $PM_{2.5}$ and ozone with a normalized mean bias of 6.77% and −3.04% respectively. The daily maximum evaluation of ozone during the ozone season yields a normalized mean gross error of 20.47%. Considering all the monitoring stations, the highest bias for the ozone seasonal daily maximum is 61%, the minimum is −42%. These values, computed in each of the seven U.S. regions that characterize the discrete application of the ozone CRF (1), are used as limits for the model uncertainty computations. The annual mean $PM_{2.5}$ modeling bias for all stations exhibits a maximum value of 108% and a minimum of −67%: as noted in

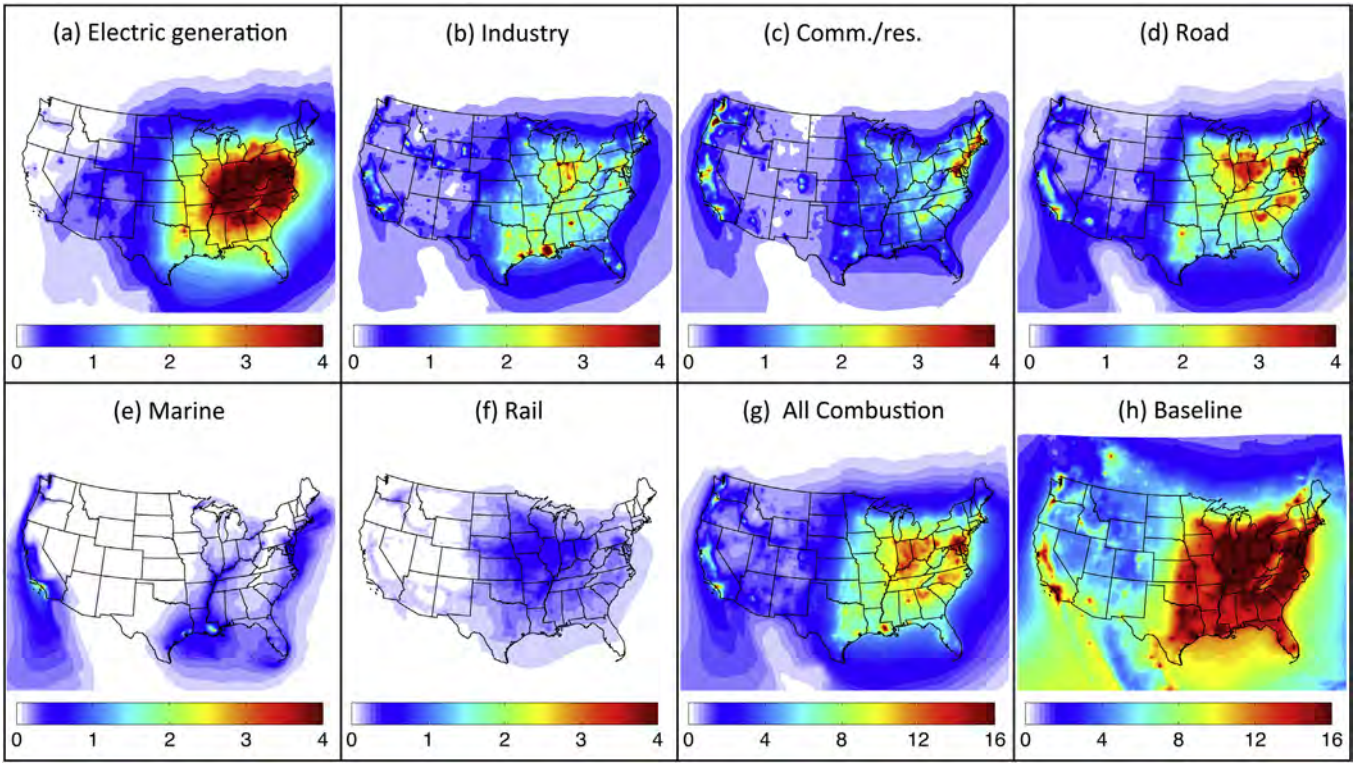

Fig. 1. Annual average ground-level $PM_{2.5}$ concentration (μg m^{-3}) from U.S. sources attributable to combustion emissions from (a) electric power generation; (b) industry; (c) commercial and residential sources; (d) road transportation; (e) marine transportation; (f) rail transportation; (g) sum of all combustion sources; (h) all sources (baseline case for this study). A different scale is adopted for (a–f) and (g–h).

Table 3
Population-weighted concentrations of $PM_{2.5}$ (μg m^{-3}) and ozone (ppb) attributable to combustion emissions from the six sectors considered in this study. $PM_{2.5}$ population-weighted annual mean concentration is speciated into six categories: sulfate (Sulf), nitrate (Nit), ammonium (Amm), black carbon (BC), organics (Org) and unspeciated (Uns). The total concentration of $PM_{2.5}$ is displayed in the second last column of the table. The PM concentrations are annually averaged while the ozone concentration is evaluated as daily maximum averaged over the ozone season (Apr–Sept).

Sector	$PM_{2.5}$							Ozone
	Sulf	Nit	Amm	BC	Org	Uns	Total $PM_{2.5}$	
Electric power generation	1.13	0.05	0.36	0.01	0.48	0.24	2.27	2.15
Industry	0.41	0.19	0.19	0.04	0.42	0.52	1.78	2.06
Commercial/residential	0.13	0.12	0.08	0.08	0.93	0.47	1.82	0.67
Road transportation	0.10	0.61	0.25	0.27	0.98	0.08	2.30	6.90
Marine transportation	0.11	0.03	0.04	0.06	0.09	0.03	0.36	0.39
Rail transportation	0.01	0.05	0.02	0.03	0.09	0.00	0.20	0.53
Total from combustion	1.89	1.05	0.94	0.49	2.99	1.34	8.73	12.70

section 2.4, these values are used as uncertainty ranges in the CMAQ $PM_{2.5}$ evaluation.

3.2. $PM_{2.5}$ impacts

Annual average ground-level $PM_{2.5}$ attributable to U.S. emissions from the different sectors considered in this study is shown in Fig. 1. The general distribution of particulate matter concentrations highlights the clustering of anthropogenic activities along the coastlines and in the Midwest regions of the U.S.

Table 3 shows the population-weighted annual mean concentrations of $PM_{2.5}$ (together with its composite species) and ozone attributable to the different sectors. Road transportation is responsible for a $PM_{2.5}$ population-weighted concentration of 2.30 μg m^{-3} in U.S., representing the largest contributor to PM-related impacts. Most of the particulate matter attributable to road transport emissions is organic (0.98 μg m^{-3}) followed by nitrate aerosol (0.61 μg m^{-3}): this reflects the fact that onroad mobile emissions are the largest source of NO_x in the U.S., as shown in Table 1. Vehicle emissions are also the largest contribution to population-weighted black carbon concentrations (0.27 μg m^{-3}). The change in black carbon concentration attributable to road vehicles in the U.S. is shown in Fig. 2a. BC concentrations peak in major cities where the traffic is higher, in contrast to total $PM_{2.5}$ concentrations (Fig. 1d) which are more diffuse due to the inclusion of secondary particulate matter. For this reason, black carbon from road emissions has a relatively high adverse health impact with respect to other PM species.

Electric power generation is responsible for a population-weighted annual mean $PM_{2.5}$ concentration of 2.27 μg m^{-3}. Given

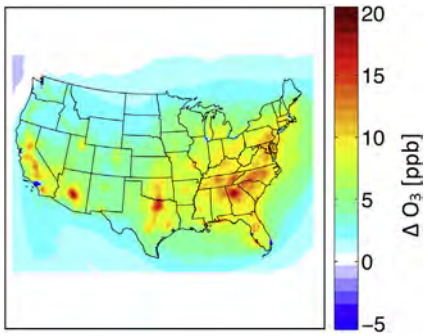

Fig. 3. Variation of mean (Apr–Sept) daily maximum ozone concentration (ppb) due to road transportation emissions in 2005.

the discrete distribution of power plants, the contribution of this sector is less ubiquitous with respect to road transportation (Fig. 1a), being less relevant on the western regions. Power plants account for 16% of NO_x emissions and 70% of SO_2 emissions in the U.S. (Table 1). Of the 9.46 million tons of sulfur dioxide emitted in 2005, about 95% comes from coal-fired power plants (NRDC, 2007) which represent the largest source of electricity in the U.S. (U.S. EIA, 2012).

Eastern power plants generally use coal with higher sulfur content than western power plants (U.S. EIA, 2002). This trend is shown in Fig. 2b, which displays the ground-level annual mean sulfate concentration attributable to electric generation. In the Midwest states, the sulfate concentration exhibits peaks of 3.5 μg m^{-3}, which account for the 1.13 μg m^{-3} population-weighted concentration of sulfate due to the electric sector. Yim and Barrett (2012) reported a population-weighted mean annual sulfate concentration of about 0.25 μg m^{-3} in the UK, showing a significantly smaller impact of the electric generation sector in this country with respect to what we found in the U.S. This is partially due to the fact that the largest power plants in the UK are generally located relatively far away as well as downwind from highly populated regions.

Combustion emissions from commercial and residential sources generate a mean annual population-weighted $PM_{2.5}$ concentration of 1.82 μg m^{-3}, mostly composed of organic particulate matter (0.93 μg m^{-3}). Due to the nature of these sources, the peaks in commercial/residential contributions occur in the most densely populated areas of the east and the west coast (Fig. 1c).

Fig. 1b shows mean $PM_{2.5}$ concentrations due to emissions from industrial activities, which account for a population-weighted annual concentration of 1.78 μg m^{-3}. The concentration distribution exhibits peaks in the Midwest industrial area between Chicago and Detroit, and in the regions around Philadelphia, Atlanta and Los Angeles. The largest contributions occur in the coastline of the U.S. Gulf Coast connecting Mobile (AL), New Orleans (LA) and Houston (TX). The high concentration of industry-attributable $PM_{2.5}$ in this

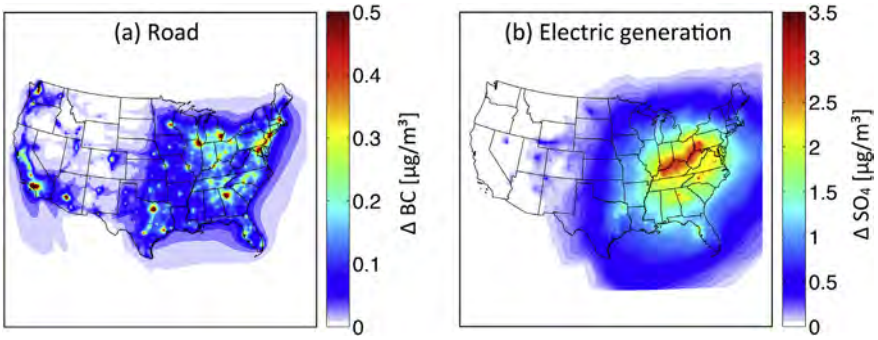

Fig. 2. Annual average ground-level concentration (in μg m^{-3}) in the U.S. of (a) black carbon (BC) due to road transportation; (b) SO_4 due to electric power generation.

Table 4
Premature deaths [90% confidence interval] in the U.S. in 2005 due to long-term exposure to $PM_{2.5}$ and ozone associated to combustion emissions from different sectors.

Sector	$PM_{2.5}$	O_3
Electric power generation	52,200 [23,400–94,300]	1700 [−250–3700]
Industry	40,800 [18,300–73,700]	1750 [−30–3500]
Commercial/residential	41,800 [18,700–75,500]	350 [−50–750]
Road transportation	52,800 [23,600–95,300]	5250 [−850–11,100]
Marine transportation	8300 [3700–15,000]	530 [−50–1100]
Rail transportation	4500 [2000–8100]	540 [−100–1200]
Aviation (Yim et al., 2013)[a]	1200 [550–2600]	155 [71–260]
Total from combustion[b]	200,400 [89,700–361,900]	10,100 [−1300–21,400]

[a] Refers to global full flight emission impact in the U.S., using the same CRFs described in Section 2.4.
[b] Excluding aviation.

region is related to the presence of the largest oil refineries in the United States (U.S. EIA, 2004).

Mean annual concentrations of particulate matter due to marine emissions are shown in Fig. 1e. Emission sources are considered only within the maritime exclusive economic zone (200 nmi off the coastline, plus maritime boundaries with adjacent/opposite countries), and Southern California exhibits their largest impact in terms of $PM_{2.5}$ concentration. Particulate matter forming in this region as a consequence of maritime emissions is then substantially advected to the southeast. Locally significant marine transportation-attributable $PM_{2.5}$ concentrations span along all the U.S. coastlines and along the navigable portions of the Mississippi and Ohio rivers. The population-weighted annual average concentration of total $PM_{2.5}$ is 0.38 μg m^{-3}, and is almost equally distributed between different PM species.

Finally, Fig. 1f shows the $PM_{2.5}$ concentration due to rail emissions: rail-attributable particulate matter spreads relatively

Table 5
Number of premature mortalities (NM) and mortality rate (MR) per year due to $PM_{2.5}$ concentrations attributable to different sectors in the 48 states of the CONUS (plus District of Columbia). Mortality rate (MR) corresponds to number of deaths per year per 100,000 people within the state.

State	Electric gen		Industry		Comm/Res		Road		Marine		Rail	
	NM	MR	NM	MR	NM	MR	NM	MR	NM	MR	NM	MR
Alabama	1242	27.3	833	18.3	509	11.2	766	16.8	86	1.9	83	1.8
Arizona	127	2.5	269	5.3	386	7.6	616	12.1	41	0.8	37	0.7
Arkansas	630	23.7	410	15.4	219	8.2	411	15.4	56	2.1	72	2.7
California	468	1.3	4834	13.9	6459	18.6	5726	16.4	3484	10.0	280	0.8
Colorado	177	4.1	160	3.7	388	9.0	264	6.2	5	0.1	24	0.6
Connecticut	473	13.9	332	9.7	821	24.1	697	20.5	62	1.8	25	0.7
Delaware	248	31.4	162	20.5	179	22.7	230	29.2	35	4.4	12	1.6
DC	187	35.1	76	14.2	164	30.8	150	28.2	7	1.3	8	1.5
Florida	2402	15.1	1372	8.6	1045	6.6	1852	11.7	459	2.9	106	0.7
Georgia	2335	28.3	1232	15.0	1161	14.1	1809	22.0	103	1.2	141	1.7
Idaho	13	1.0	127	9.6	112	8.5	68	5.1	4	0.3	10	0.8
Illinois	3161	25.0	2840	22.5	1551	12.3	3135	24.8	176	1.4	437	3.5
Indiana	2032	32.8	1661	26.8	838	13.5	1639	26.5	100	1.6	209	3.4
Iowa	528	17.7	379	12.7	235	7.9	476	16.0	22	0.7	101	3.4
Kansas	448	16.2	365	13.2	211	7.6	396	14.3	15	0.5	99	3.6
Kentucky	1642	39.7	726	17.6	556	13.5	886	21.4	86	2.1	101	2.4
Louisiana	826	18.2	1133	24.9	319	7.0	568	12.5	314	6.9	74	1.6
Maine	98	7.5	81	6.2	192	14.7	105	8.1	14	1.1	3	0.3
Maryland	1885	34.9	987	18.3	1505	27.9	1558	28.8	104	1.9	96	1.8
Massachusetts	821	12.8	1211	18.8	1775	27.6	1368	21.3	131	2.0	42	0.7
Michigan	2289	22.3	1858	18.1	1050	10.2	2484	24.2	103	1.0	196	1.9
Minnesota	580	11.6	664	13.3	559	11.2	777	15.6	38	0.8	122	2.4
Mississippi	684	23.7	431	14.9	241	8.3	414	14.3	82	2.8	56	1.9
Missouri	1329	23.3	873	15.3	588	10.3	1048	18.4	82	1.4	196	3.4
Montana	8	0.8	24	2.7	26	2.8	18	1.9	1	0.1	4	0.5
Nebraska	227	13.1	168	9.7	92	5.3	193	11.1	6	0.3	57	3.3
Nevada	47	2.4	109	5.6	98	5.0	104	5.3	16	0.8	10	0.5
New Hampshire	137	10.9	176	14.0	279	22.2	185	14.7	12	1.0	6	0.5
New Jersey	1885	22.2	1260	14.8	2341	27.6	2420	28.5	328	3.9	78	0.9
New Mexico	63	3.4	79	4.4	85	4.7	97	5.3	5	0.3	14	0.8
New York	3744	19.8	2400	12.7	4442	23.5	4730	25.1	559	3.0	176	0.9
North Carolina	2570	32.0	1059	13.2	1196	14.9	1742	21.7	115	1.4	134	1.7
North Dakota	35	5.3	26	4.0	19	2.9	25	3.8	1	0.1	9	1.4
Ohio	4223	36.1	2024	17.3	1783	15.3	3054	26.1	204	1.7	328	2.8
Oklahoma	536	15.3	466	13.3	224	6.4	489	14.0	26	0.7	78	2.2
Oregon	35	1.0	238	6.8	1263	36.3	252	7.3	82	2.3	24	0.7
Pennsylvania	3864	31.1	2118	17.1	2431	19.6	3114	25.1	274	2.2	193	1.6
Rhode Island	145	14.1	128	12.5	237	23.1	178	17.3	20	2.0	6	0.6
South Carolina	1196	29.3	532	13.1	575	14.1	846	20.8	60	1.5	66	1.6
South Dakota	70	9.2	55	7.2	29	3.8	51	6.7	1	0.2	14	1.9
Tennessee	1787	31.1	928	16.2	641	11.2	1053	18.3	95	1.7	117	2.0
Texas	2835	13.4	3583	17.0	1869	8.8	3239	15.3	642	3.0	317	1.5
Utah	58	2.6	88	3.9	107	4.8	145	6.5	6	0.3	10	0.5
Vermont	57	9.2	36	5.8	69	11.2	56	9.1	3	0.5	3	0.5
Virginia	2433	33.8	1153	16.0	1416	19.7	1608	22.4	121	1.7	120	1.7
Washington	50	0.8	308	5.1	1625	26.9	554	9.2	149	2.5	38	0.6
West Virginia	683	36.5	269	14.4	243	13.0	307	16.4	23	1.2	31	1.6
Wisconsin	981	17.9	728	13.3	770	14.1	1083	19.8	52	1.0	130	2.4
Wyoming	15	3.0	23	4.7	9	1.8	10	2.1	1	0.1	3	0.6

Table 6
Number of premature mortalities (NM) and mortality rate (MR) per year due to $PM_{2.5}$ concentrations attributable to different sectors in the 20 most populous metropolitan areas (M) and cities (C) of the CONUS (2005 data). Mortality rate (MR) corresponds to number of deaths per year per 100,000 people within the state.

City/MA	Electric gen		Industry		Comm/Res		Road		Marine		Rail	
	NM	MR	NM	MR	NM	MR	NM	MR	NM	MR	NM	MR
New York City (M)	2571	20.3	1713	13.5	3555	28.0	3615	28.5	483	3.8	103	0.8
Los Angeles (M)	137	1.5	1854	20.6	1891	21.1	2092	23.3	1505	16.8	90	1.0
Chicago (M)	1102	22.7	1378	28.4	716	14.8	1379	28.4	56	1.1	171	3.5
Detroit (M)	657	23.2	593	21.0	292	10.3	790	27.9	28	1.0	46	1.6
Philadelphia (M)	573	27.1	404	19.1	535	25.3	591	28.0	79	3.7	25	1.2
Boston (M)	242	12.4	546	28.0	682	35.0	540	27.7	47	2.4	13	0.7
Washington (M)	655	35.2	290	15.6	560	30.1	533	28.6	24	1.3	32	1.7
San Jose (M)	11	0.6	202	11.0	433	23.4	199	10.8	126	6.8	8	0.4
Houston (M)	255	14.1	506	27.9	258	14.2	304	16.8	158	8.7	25	1.4
San Diego (M)	56	3.4	143	8.7	339	20.7	288	17.5	201	12.3	12	0.7
Minn.-Saint Paul (M)	203	12.5	318	19.5	253	15.5	341	20.9	13	0.8	43	2.6
Dallas (M)	280	17.4	329	20.5	209	13.0	374	23.2	20	1.3	29	1.8
Baltimore (M)	475	34.7	368	26.9	441	32.2	430	31.4	35	2.6	25	1.8
Phoenix (C)	34	2.6	89	7.0	141	11.1	225	17.7	11	0.8	11	0.8
Cleveland (M)	466	36.8	222	17.6	222	17.5	384	30.3	32	2.5	37	2.9
Miami (C)	127	10.2	70	5.6	80	6.4	128	10.3	61	4.9	5	0.4
Denver (M)	53	4.4	50	4.2	128	10.7	103	8.6	1	0.1	7	0.6
Saint Louis (M)	280	26.8	204	19.5	141	13.5	235	22.5	22	2.1	31	2.9
Kansas City (C)	208	20.1	163	15.8	109	10.6	199	19.2	8	0.7	47	4.5

uniformly in the central-eastern part of the U.S., with a peak in the Midwest. Yearly averaged population-weighted concentration of rail-attributable $PM_{2.5}$ is 0.20 $\mu g\ m^{-3}$.

3.3. Ozone impacts

The impact on ozone concentrations is related to the atmospheric concentrations of VOC and NO_x. Fig. 3 shows the average daily maximum concentration of ozone attributable to road transportation emissions. Daily maximum ozone is temporally averaged only during the ozone season (Apr–Sep), consistent with EPA practice. Road mobile emissions induce a domain-wide increase in daily maximum seasonal ozone concentrations, except for some major urban areas (e. g. Miami), where the high background NO_x concentrations account for a decrease in the ozone concentrations due to the additional NO_x emitted by road vehicles.

Road transportation provides the most significant impact over ozone exposure among the combustions emission sources considered in this study. From Table 3, the population-weighted mean daily maximum ozone concentration due to vehicle emissions is 6.90 ppb, about three times larger than the population-weighted concentration change due to electric generation (2.15 ppb) and industry (2.06 ppb). Commercial/residential activities, as well as shipping and rail emissions, have an impact on the mean daily maximum ozone concentration below 1 ppb.

3.4. Health impacts

Premature deaths from cardiovascular diseases and lung cancer due to long-term exposures to $PM_{2.5}$ attributable to each sector are evaluated by applying the CRF described in Section 2.4, and are given in Table 4. Aggregated combustion emissions account for a total of about 200,000 (90% CI: 90,000–361,000) $PM_{2.5}$-related premature mortalities per year in the U.S. This result is comparable with total mortalities estimated by similar studies (U.S. EPA, 2011a; Fann et al., 2012). The distribution of early deaths among the different sectors reflects the population-weighted average $PM_{2.5}$ sector-attributable concentrations shown in Table 3.

The two largest contributors to $PM_{2.5}$-related premature deaths in the U.S. are road transport and power generation, accounting for 53,000 (90% CI: 24,000–95,000) and 52,000 (90% CI: 23,000–94,000) early deaths per year, respectively.

Commercial/residential sources and industry account for 42,000 (90% CI: 19,000–76,000) and 41,000 (90% CI: 18,000–74,000) early deaths, respectively. About 8000 (90% CI: 4000–15,000) deaths per year are attributable to marine transport and 4500 (90% CI: 2000–8000) to rail transport. Aviation mortalities are included in the table as estimated by Yim et al. (2013): a total of 1200 (90% CI: 550–2600) $PM_{2.5}$-related mortalities per year are attributable to full flight aviation emissions in North America.

Table 5 allocates the $PM_{2.5}$-related premature mortalities for each sector shown in Table 4 in the 48 states (and the District of Columbia) of the CONUS. This table displays for each state both the absolute number of premature deaths per year and the mortality rate, defined as number of early deaths per year per 100,000 people within the state.

CMAQ gridded results for each sector are attributed to each state using the code ArcGIS (ESRI, 2008). In terms of absolute impact of $PM_{2.5}$ combustion emissions, the most affected region is California, with about 21,000 early deaths per year. Of these, about 12,000 come from both commercial/residential sources and road transportation, and ~5000 from industry. About 3500 premature deaths per year in this state are attributable to marine transportation emissions, which exhibit a peak in Southern California (Fig. 1e).

The data in Table 5 show a large impact of electric generation emissions in the central-eastern U.S. and in the Midwest. This reflects the trend shown in Fig. 2b for power generation-related sulfate concentrations. In particular, with a mortality rate (MR) of about 40 premature deaths per year per 100,000 inhabitants in Kentucky, electric generation is the sector responsible for the highest mortality rate among the U.S. states.

Road transportation, consistent with its annual mean $PM_{2.5}$ concentration map (Fig. 1d), exhibits the most widespread distribution of sector-attributable premature deaths among the U.S. states. In terms of relative impacts, the state characterized by the highest relative mortality due to all the sectors is Maryland, with about 114 early deaths per year every 100,000 inhabitants.[1]

[1] It should be noted that the total number of early deaths given in Table 5 for each sector does not exactly coincide with the values of Table 4 for the whole U.S. This is due to slight inaccuracies in the allocation of the gridded population distribution within state boundaries, which yields an average error of 0.9% in the estimate of the cumulative number of deaths per each sector.

Table 7
Number of premature mortalities (NM) and mortality rate (MR) per year due to ozone concentrations attributable to different sectors in the 48 states of the CONUS (plus District of Columbia). Mortality rate (MR) corresponds to number of deaths per year per 100,000 people within the state.

State	Electric gen		Industry		Comm/Res		Road		Marine		Rail	
	NM	MR	NM	MR	NM	MR	NM	MR	NM	MR	NM	MR
Alabama	97	2.13	69	1.51	14	0.31	240	5.27	22	0.49	24	0.52
Arizona	41	0.81	47	0.92	19	0.37	403	7.94	16	0.32	30	0.59
Arkansas	50	1.90	46	1.72	6	0.21	120	4.53	15	0.56	18	0.66
California	8	0.02	43	0.12	22	0.06	209	0.60	49	0.14	12	0.03
Colorado	27	0.62	23	0.54	3	0.08	57	1.33	1	0.03	7	0.17
Connecticut	−2	−0.06	−2	−0.07	−1	−0.04	−12	−0.35	−1	−0.02	0	−0.01
Delaware	−1	−0.08	−1	−0.07	0	−0.03	−3	−0.36	0	−0.03	0	−0.02
DC	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Florida	175	1.10	97	0.61	82	0.52	191	1.20	9	0.06	22	0.14
Georgia	108	1.31	77	0.94	19	0.23	396	4.80	24	0.30	28	0.34
Idaho	2	0.15	6	0.43	1	0.07	16	1.20	1	0.07	2	0.17
Illinois	12	0.09	9	0.07	2	0.01	24	0.19	3	0.02	5	0.04
Indiana	−1	−0.01	0	−0.01	0	0.00	−3	−0.04	0	0.00	0	0.00
Iowa	46	1.56	36	1.20	6	0.20	97	3.24	5	0.18	19	0.64
Kansas	44	1.57	43	1.56	4	0.16	88	3.20	5	0.16	17	0.61
Kentucky	24	0.58	13	0.30	2	0.06	48	1.15	5	0.11	5	0.13
Louisiana	65	1.44	109	2.40	8	0.18	163	3.58	75	1.66	17	0.38
Maine	−1	−0.05	−1	−0.07	−1	−0.04	−5	−0.36	0	−0.04	0	−0.01
Maryland	−4	−0.07	−3	−0.06	−1	−0.02	−16	−0.29	−1	−0.02	−1	−0.02
Massachusetts	−3	−0.05	−2	−0.04	−2	−0.03	−4	−0.06	−1	−0.02	0	0.00
Michigan	−1	−0.01	−1	−0.01	0	0.00	−3	−0.03	0	0.00	0	0.00
Minnesota	54	1.08	42	0.84	9	0.18	119	2.39	6	0.12	21	0.42
Mississippi	51	1.76	50	1.73	6	0.22	135	4.68	26	0.91	16	0.55
Missouri	72	1.25	48	0.85	8	0.14	144	2.52	12	0.21	26	0.46
Montana	2	0.20	2	0.26	0	0.04	8	0.92	1	0.06	2	0.17
Nebraska	26	1.48	23	1.33	2	0.14	48	2.75	2	0.11	12	0.70
Nevada	2	0.12	4	0.19	1	0.08	20	1.05	1	0.07	2	0.11
New Hampshire	−1	−0.05	−1	−0.05	0	−0.03	−4	−0.28	0	−0.01	0	−0.01
New Jersey	−2	−0.03	−3	−0.04	−2	−0.02	−3	−0.04	1	0.01	0	−0.01
New Mexico	40	2.22	55	3.03	5	0.30	127	7.02	5	0.28	19	1.06
New York	−7	−0.04	−9	−0.05	−5	−0.03	−16	−0.09	2	0.01	−2	−0.01
North Carolina	150	1.86	98	1.22	31	0.38	489	6.08	32	0.40	33	0.41
North Dakota	8	1.16	5	0.79	1	0.11	12	1.78	0	0.07	3	0.52
Ohio	−2	−0.02	−1	−0.01	0	0.00	−6	−0.05	0	0.00	0	0.00
Oklahoma	72	2.06	95	2.71	9	0.25	222	6.33	13	0.37	25	0.71
Oregon	4	0.10	7	0.21	4	0.13	36	1.03	8	0.23	3	0.08
Pennsylvania	−10	−0.08	−7	−0.06	−3	−0.02	−37	−0.30	−1	−0.01	−2	−0.02
Rhode Island	−1	−0.07	−1	−0.06	0	−0.04	−4	−0.40	−1	−0.05	0	−0.01
South Carolina	73	1.79	53	1.30	15	0.36	260	6.38	20	0.50	18	0.43
South Dakota	12	1.58	10	1.30	1	0.14	21	2.75	1	0.11	6	0.73
Tennessee	101	1.76	67	1.17	13	0.23	277	4.82	23	0.39	27	0.48
Texas	252	1.19	495	2.34	43	0.20	1052	4.98	163	0.77	88	0.42
Utah	9	0.42	6	0.27	1	0.06	27	1.21	1	0.05	3	0.13
Vermont	0	−0.07	0	−0.07	0	−0.03	−2	−0.39	0	−0.02	0	−0.02
Virginia	39	0.54	22	0.31	7	0.09	69	0.95	−20	−0.28	7	0.10
Washington	3	0.05	5	0.08	4	0.06	29	0.48	3	0.05	2	0.04
West Virginia	−1	−0.03	0	−0.01	0	−0.01	−2	−0.08	0	0.00	0	0.00
Wisconsin	15	0.27	12	0.21	3	0.05	33	0.61	3	0.05	6	0.10
Wyoming	4	0.82	4	0.72	0	0.07	7	1.37	0	0.05	2	0.31

Table 6 shows the same results as Table 5 for the 20 most populous metropolitan areas in the U.S. Urban population data are retrieved from the National Atlas of the United States, 2005. As expected for all metropolitan areas, road transportation and commercial/residential sources have the largest and most uniformly distributed impact on all cities. The highest peaks of the $PM_{2.5}$-related health impacts due to vehicle emissions are found in the major East coast cities: New York (MR ~ 28.5), Washington (MR ~ 28.6) and Baltimore (MR ~ 31.4). The city of Baltimore in particular is characterized by the highest total mortality rate from all combustion sources: about 130 early deaths attributable to $PM_{2.5}$ per year per 100,000 inhabitants. The highest absolute all-combustion sources impact is in New York, with about 12,000 total mortalities per year.

Of the set of 5695 cities considered, the highest $PM_{2.5}$-attributable all-combustion mortality rate (MR ~144) has been found in Donaldsonville, LA. Here the presence of nine oil refineries within a 70-km radius, for a total production of ~2.2 million barrels per day (NREL, 2012), accounts for a mortality rate by industrial sources of ~81 early deaths per year per 100,000 people.

Table 4 also includes premature mortalities due to ozone concentrations attributable to the different sectors. Aggregated combustion emissions account for about 10,100 (90% CI: −1300 to 21,400) ozone-related premature deaths in the U.S. in 2005. As with $PM_{2.5}$, the aggregate ozone mortality estimate is consistent with previous national emissions assessments in the U.S. (U.S. EPA, 2011a; Fann et al., 2012). The negative lower bound is a consequence of the ozone depletion occurring in densely populated cities, due to NO_x emissions in NO_x-saturated environments.

The main contributor is road transportation, which is responsible for more than half of the ozone-related mortalities (~5250). Both electric generation and industry account for about 1800 mortalities per year. Commercial/residential, marine and rail transport account for about 350, 530 and 540 ozone-related

mortalities annually, respectively. It is noted that, despite their relatively large contributions to $PM_{2.5}$ mortalities with respect to the other sectors, commercial and residential sources contribute only to a fraction of the total ozone-related early deaths. This can be explained by considering the NO_x emission attributions given in Table 1. Road transportation represents the single largest contributor to NO_x emissions (accounting for 38.5% of the total). Industry and electric generation both give a similar contribution to NO_x emissions. This trend is reflected in the national pattern of ozone-related mortalities shown in Table 4.

Similarly to the previous tables for $PM_{2.5}$, Table 7 and Table 8 provide the number of early deaths per year and the mortality rate due to ozone exposure as a consequence of emissions from the six sectors considered. Table 7 shows the data for each U.S. state, while Table 8 sorts the results for the 20 most populous metropolitan areas. The correlation between high ozone levels and high sunlight exposure, together with differences in emissions and background VOC and NO_x concentrations, account for the uneven distribution of ozone-related mortalities between northern and southern states.

More than 20% of the ozone-related mortalities from all sectors (~2100 early deaths) occur in Texas, mainly as a consequence of road transportation and industrial emissions. The second most affected state is North Carolina, with about 800 ozone-related early deaths per year, half of which attributable to vehicle emissions. Smaller states with high percentage of urban areas (e. g., Maryland, Connecticut) are characterized by an ozone-related mortality reduction due all-sectors emissions. In these regions, ozone is generally depleted by additional NO_x emissions. The same principle applies to many of the metropolitan areas considered in Table 8.

4. Discussion

The spatial distribution and speciation of $PM_{2.5}$ impacts per sector can be used to inform the design of sector-specific emission mitigation measures. Premature mortalities from sulfate attributable to power plants represent approximately half of the ~52,000 mortalities from the sector. These mortalities are mainly related to SO_x emissions from coal power plants, and could be reduced by promoting the purchase of low-sulfur content coal from the western deposits in the Powder River Basin in Wyoming and Montana (Stavins and Schmalensee, 2012), the introduction of lime scrubbers, or the adoption of alternative energy sources (e. g. natural gas, as forecasted by the U.S. EIA, 2012). Similarly, the mortalities related to marine combustion emissions (of which about one third is related to sulfate concentrations) could be reduced by enforcing limits to the sulfur content of bunker fuel used in ship engines. Regulations to this effect have recently been put in place by the International Maritime Organization (IMO, 2010). In 2010 a limit of 1% fuel sulfur content for the North America Emission Control Area (ECA) was established, to be lowered to 0.1% in 2015.

In using the results of this study to inform potential mitigation measures, it is important to note that premature mortality estimates are calculated assuming equal toxicity amongst the different types of particulate matter. Recent epidemiological studies (Lippmann and Chen, 2009; Levy et al., 2012) suggest that differential toxicity amongst PM species may be significant. In an extensive multi-site time-series analysis, Levy et al. (2012) showed differences in the correlations between changes in hospital admissions and concentrations of different types of $PM_{2.5}$, with black carbon showing the highest relative health impact. Furthermore, a recent ACS cohort analyses (Lippman, 2010) indicate that $PM_{2.5}$ correlations with premature mortality risk may vary with source category, with coal and traffic sources having the most significant associations. Despite these findings, no epidemiological study to date has provided a conclusive assessment of the relative toxicity of different $PM_{2.5}$ components, sufficient to develop CRFs accounting for those differences [as per Levy et al. (2012) and current EPA practice]. It is therefore possible that future CRFs will be able to describe particulate matter health impacts by weighting PM species. Table 3 of the present study provides data appropriate for such a calculation.

An assessment of the health impacts from $PM_{2.5}$ and ozone concentrations attributable to different source categories in the US has been performed in parallel with the present study by Fann et al. (2013), who adopt a source apportionment approach to allocate the concentrations of $PM_{2.5}$ and ozone among various different source categories. Their source categories follow the NEI source classification scheme, whereas we have reprocessed inventories to correspond to what may be termed “economic” sectors. For example, the “industrial” sources in this study are split between “industrial point sources” and “area sources” in Fann

Table 8
Number of premature mortalities (NM) and mortality rate (MR) per year due to ozone concentrations attributable to different sectors in the 20 most populous metropolitan areas (M) and cities (C) of the CONUS (2005 data). Mortality rate (MR) corresponds to number of deaths per year per 100,000 people within the state.

City/MA	Electric Gen		Industry		Comm/Res		Road		Marine		Rail	
	NM	MR	NM	MR	NM	MR	NM	MR	NM	MR	NM	MR
New York City (M)	−2.22	−0.017	−4.66	−0.037	−2.67	−0.021	3.76	0.030	2.93	0.023	−0.53	−0.004
Los Angeles (M)	0.24	0.003	1.42	0.016	1.52	0.017	0.95	0.011	0.02	0.000	−0.17	−0.002
Chicago (M)	−0.13	−0.003	−0.12	−0.002	0.01	0.000	0.23	0.005	−0.01	0.000	0.06	0.001
Detroit (M)	−0.02	−0.001	−0.02	−0.001	−0.01	0.000	−0.02	−0.001	0.00	0.000	0.00	0.000
Philadelphia (M)	−0.16	−0.008	−0.15	−0.007	−0.07	−0.003	−0.75	−0.035	−0.06	−0.003	−0.03	−0.002
Boston (M)	−0.42	−0.021	0.10	0.005	−0.19	−0.010	8.96	0.459	0.19	0.010	0.21	0.011
Washington (M)	−0.77	−0.041	−0.67	−0.036	−0.28	−0.015	−3.57	−0.192	−0.11	−0.006	−0.21	−0.011
San Jose (M)	0.21	0.012	1.33	0.072	0.78	0.042	5.19	0.281	6.05	0.328	0.08	0.004
Houston (M)	9.17	0.505	22.37	1.233	3.24	0.179	47.30	2.607	11.25	0.620	2.78	0.153
San Diego (M)	0.02	0.001	0.28	0.017	0.11	0.007	0.13	0.008	−0.50	−0.031	0.05	0.003
Minn.-Saint Paul (M)	9.40	0.577	6.20	0.380	1.63	0.100	21.49	1.318	0.87	0.053	3.54	0.217
Dallas (M)	4.15	0.258	6.22	0.386	0.60	0.037	16.92	1.051	1.46	0.091	1.19	0.074
Baltimore (M)	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
Phoenix (C)	4.48	0.351	6.68	0.523	3.89	0.305	71.07	5.569	2.53	0.198	4.65	0.364
Cleveland (M)	−0.08	−0.006	−0.06	−0.005	−0.02	−0.002	−0.03	−0.002	0.03	0.003	0.01	0.001
Miami (C)	0.83	0.067	8.09	0.651	12.71	1.024	−94.1	−7.582	−13.11	−1.056	0.41	0.033
Denver (M)	3.28	0.275	2.77	0.231	0.68	0.057	11.07	0.926	0.18	0.015	0.93	0.078
Saint Louis (M)	−0.04	−0.004	−0.03	−0.003	−0.01	−0.001	−0.19	−0.018	−0.01	−0.001	−0.01	−0.001
Kansas City (C)	8.55	0.827	5.03	0.486	0.83	0.081	14.76	1.429	0.83	0.080	3.01	0.291

et al. (2013), where their area sources in turn also include part of the commercial/residential emissions considered in this study. Here we make a comparison for $PM_{2.5}$-related early deaths insofar as possible using Table 3 of the Fann et al. (2013) SI and assuming a nominal 12 life years lost per premature mortality for the purposes of this comparison. We note that these comparisons are not like-for-like due to the different inventory processing applied (as well as different meteorology and air quality models, and apportionment approach) and it is not clear the extent to which comparisons are appropriate. For power generation [Fann et al. (2013): electricity generating units] we estimate 52,200 early deaths per year, compared to their 51,700 using our conversion. For mobile sources [approximately our road transportation, marine transportation, rail transportation and aviation] we estimate 66,800 early deaths per year, cf. their estimate of 36,300. We note that our aircraft estimate includes cruise emissions, whereas theirs is based on a different inventory and only for landing and takeoff emissions. For industry [Fann et al. (2013): all industrial sub-categories except electricity generating units] we estimate 40,800 cf. their 22,400. However, our definition of industry includes some of their "area sources" so an upper bound on their early deaths would be 42,800. In total (excluding non-anthropogenic and transboundary pollution) Fann et al. (2013) estimates 148,000 early deaths per year, cf. our 200,000 early deaths per year. This implies that our estimates are broadly ~35% higher, although firm conclusions about individual sectors cannot be made. Additionally, we infer 16 life years lost per premature mortality for electricity generating units from their work which would expand the difference by ~30%, while our accounting for low $PM_{2.5}$ modeling biases in our probabilistic approach would serve to reduce the effective differences by ~25%. On a relative basis, we observe that in both assessments electric generation accounts for about 25% of the total $PM_{2.5}$ premature deaths. The relative importance of the aggregated transportation sectors (road, marine, rail and aviation) in the present study is higher (~33% versus ~20%) than the "mobile" sector considered in Fann et al. (2013).

5. Conclusions

Combustion emissions in the U.S. are found to be responsible for ~200,000 premature mortalities due to long-term exposure to increased $PM_{2.5}$ concentrations, and ~10,600 premature mortalities due to exposure to increased ozone concentrations. The totals computed do not consider non-linearities in the model response (e. g., in the formation of secondary $PM_{2.5}$). This effect is expected to be relatively small, potentially yielding an underestimation in total mortalities of the order of 6%, as found in a study using an analogous methodology in the United Kingdom (Yim and Barrett, 2012).

Among the different sectors considered in this study, road transportation accounts for the largest number of early mortalities, ~53,000 $PM_{2.5}$-related and ~5300 ozone-related. For comparison, we consider that in 2005 the number of fatalities related to car accidents in the U.S. was ~43,500 (U.S. DOT, 2012). This suggests that the air quality impact of road transportation in terms of premature deaths may likely exceed the number of fatal accidents by about 30%. It is documented (U.S. DOT, 2012) that about 40% of the fatal accidents involve people in the 0–44 years range, corresponding to a loss of about 35 life years per fatality. Emissions instead generally affect people at older ages, with an average loss of ~12 years per mortality (COMEAP, 2010), yielding a total of 0.70 million life years lost from both $PM_{2.5}$ and ozone exposure per year. This means that car accidents may still be the leading cause of loss of life years, despite the smaller number of fatalities. These issues related to the use of premature mortalities as a metric to assess the health burden related to air pollution are discussed in COMEAP (2010).

Considering concentrations of different types of $PM_{2.5}$, road vehicles account for a population-weighted concentration of black carbon larger than the sum of all the other sectors (Table 3).

Power generation emissions results in adverse health impacts similar to road transportation in terms of premature mortalities (Table 3). A large extent of this impact is related to sulfur dioxide emissions from coal-fired power plants. The population-weighted concentration of 1.13 $\mu g\ m^{-3}$ of sulfate due to electric generation is the highest among all the $PM_{2.5}$ species for all the sectors considered (Table 2). A reduction of sulfur dioxide emissions from power plants could therefore limit the adverse health impact of electric generation, and should be taken into account for future U.S. energy and air quality policies.

The extent of the impact on air quality by road transportation and electric power generation found in this assessment will drive the selection of future-year mitigation scenarios explored in Part II of the study.

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The Clean Air Benefits of Wind Energy

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Executive Summary

Wind energy is a widely available, affordable, reliable, non-emitting, readily quantifiable and verifiable, and rapidly deployable electric generation method for significantly reducing air pollution, including emissions of carbon dioxide (CO_2), nitrogen oxides (NOx) and sulfur dioxide (SO_2). Indeed, the current fleet of wind turbines in the U.S. is already reducing carbon emissions by nearly 127 million tons per year.

In May 2014, the U.S. Global Change Research Program (USGCRP)[1] issued its National Climate Assessment.[2] The report documents the existing evidence and impacts of climate change here at home, including on a regional basis as well as on specific sectors like energy and human health. Wind energy is specifically identified as one of the available mitigation options.

Similarly, the U.N. Intergovernmental Panel on Climate Change[3] issued several volumes that make up its Fifth Assessment Report[4] earlier this year, which found a need to triple or nearly quadruple electric generation from zero- and low-carbon energy resources by 2050 in order to avert the worst consequences of climate change.

The U.S. Environmental Protection Agency (EPA) also notes the following about the benefits from reducing SO_2 and NOx: "By reducing SO_2 and NO_x, many acidified lakes and streams will significantly improve so that they can once again support fish life. Visibility will improve, allowing for increased enjoyment of scenic vistas across our country, particularly in National Parks. Stress to our forests that populate the ridges of mountains from Maine to Georgia will be reduced. Deterioration of our historic buildings and monuments will be slowed. Most importantly, reductions in SO_2 and NO_x will reduce fine particulate matter (sulfates, nitrates) and ground level ozone (smog), leading to improvements in public health."[5]

In order to address the aforementioned challenges and pursuant to decisions by the U.S. Supreme Court, the EPA in June 2014 will propose a rulemaking to, for the first time ever, provide for federal limits on carbon pollution from existing power plants under section 111(d) of the Clean Air Act.[6] States will play a key role in the compliance process with the final rule, in part through the submission of state plans that will detail how generators in their states will meet the carbon pollution standards set forth by the EPA.

As detailed in this white paper, wind energy is widely available across the country as a compliance option under 111(d) and is already playing a significant role in reducing carbon emissions in nearly every state, as well as emissions of other air pollutants. Further, as also described in the following pages, wind energy is doing so affordably and reliably for consumers.

Of particular note, this paper provides state-by-state numbers, calculated using the EPA's own Avoided Emissions and generation Tool (AVERT), for the emissions reductions

[1] The USGCRP is made up of 13 federal agencies and departments.
[2] A team of more than 300 experts guided by a 60-member Federal Advisory Committee produced the report, which was extensively reviewed by the public and experts, including federal agencies and a panel of the National Academy of Sciences. The report is available online at: http://nca2014.globalchange.gov/
[3] http://www.ipcc.ch/
[4] http://www.ipcc.ch/report/ar5/index.shtml

[5] Available at: http://www.epa.gov/airmarkets/progsregs/arp/basic.html#bens
[6] For more information, see: http://www2.epa.gov/carbon-pollution-standards

attributable to the currently installed wind turbine fleet in the U.S.

Among the key findings in this paper:

- The 167.7 million megawatt-hours (MWh) of wind energy produced in the U.S. in 2013 reduced CO_2 emissions by 126.8 million tons, the equivalent of reducing power sector emissions by more than 5 percent, or taking 20 million cars off the road.

- The top 10 states by volume of carbon reductions from wind energy are: Texas, Illinois, California, Colorado, Iowa, Missouri, Oklahoma, Wisconsin, Minnesota and Wyoming.

- States achieving a reduction in carbon emissions of 10 percent or more from wind energy alone include California, Colorado, Idaho, Iowa, Kansas, Minnesota, Nebraska, Oregon, South Dakota, Vermont, and Washington State, with Oklahoma, Wisconsin and Wyoming coming in just under 10%.

- One MWh of wind energy avoids .75 tons, or 1,500 pounds, of carbon dioxide emissions on average. A typical 2 MW wind turbine avoids around 4,000-4,500 tons of carbon emissions annually, equivalent to the annual carbon emissions of more than 700 cars.

- Wind energy currently reduces SO_2 emissions by nearly 347 million pounds per year and NO_x by 214 million pounds per year.

- Wind energy saved 36.5 billion gallons of water in 2013 that would have been consumed at conventional power plants, the equivalent of roughly 116 gallons per person in the U.S., or 276 billion bottles of water, providing critical relief in drought-stricken areas.

- There are 61,110 megawatts (MW) of wind energy capacity installed in 39 states and Puerto Rico, representing more than 46,000 operational utility-scale wind turbines. There are now 16 states with 1,000 MW or more of installed wind energy capacity.

- Over the last five years, wind energy has accounted for 31 percent of all newly installed electric generating capacity, second only to natural gas. In 2012, wind energy was the largest source of all new generating capacity at 42 percent.

- In some regions, such as the Pacific Northwest, Plains states and the Midwest, wind energy has been the primary source of new capacity over the last three years, providing 60 percent or more of all new electric generating capacity. In the Upper Midwest, wind energy provided more than 80 percent of all new generating capacity from 2011-2013.

- The existing wind turbine fleet provides the electrical output equivalent to 53 average coal plants or 14 average nuclear plants.

- On an average annual basis, wind energy produces more than 25 percent of the electricity in two states, 12 percent or more in nine states, and five percent or more in 17 states.

- The average power purchase price of wind energy has fallen 43 percent over the last 5 years, with both the Energy

Information Administration and Lazard finding that wind energy is second only to a combined cycle natural gas plant in terms of lowest cost source of new electric generation.

- While other generation may need to ramp up or down to accommodate the variability of wind energy (and other far larger sources of variability on the power system like electricity demand and the sudden failure of large conventional generators), two recent studies from different regions in the U.S. document that such cycling has virtually no net effect on the emissions reductions from wind energy, with wind producing 99.8 percent of the carbon emissions savings expected of a zero emissions resource.

- Wind energy can play an even greater role in reducing emissions reductions going forward. More than a dozen utility and independent grid operator studies have found wind can reliably provide an even larger share of our electricity needs, which will, in turn, produce even larger emissions reductions. For example, an NREL study for the Eastern U.S. found that obtaining 20 percent of electricity from wind energy cut power sector carbon emissions by 25 percent, and 30 percent wind cut carbon emissions by 37 percent, relative to the baseline generation mix.

- Wind energy can continue to rapidly scale up. Since the end of 2005, the U.S. wind energy industry has doubled its installed capacity, on average, every 36 months. The U.S. industry installed a high of more than 13,000 MW in 2012, and there are currently more wind projects under construction in the U.S. than at any point in history. U.S. wind energy's five year average annual growth rate is 19.5 percent from 2009-2013.

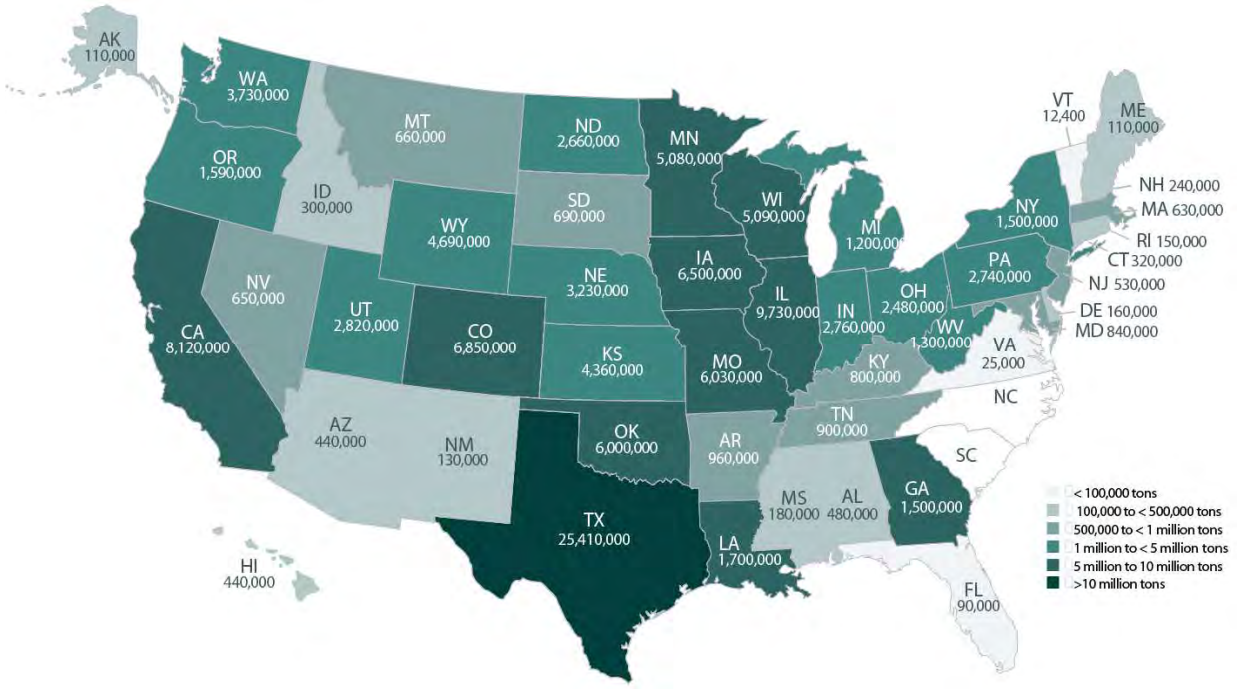

Figure 1: Wind energy's 2013 emissions reductions by state, using EPA's AVERT tool[7]

Wind energy is greatly reducing emissions of carbon dioxide and other pollutants in nearly every state.

AWEA used a new EPA modeling tool to quantify the state-by-state pollution reductions wind energy is currently providing, and the results are shown in the map and tables below. The 167.7 million megawatt-hours (MWh) of wind energy produced in the U.S. in 2013 reduced CO_2 emissions by 126.8 million short tons, the equivalent of reducing power sector emissions by more than 5 percent or taking 20 million cars off the road. These emissions savings were broadly distributed across nearly every state, accounting for the fact that wind energy is widely deployed and that many utilities in states without wind plants are purchasing wind energy from other states. Emissions savings are reported in the states where the AVERT model indicates fossil-fired power plants

[7] EPA recently released a new tool, AVERT, that allows for the calculation of emissions reductions associated with wind energy and other non-emitting solutions. EPA's AVERT tool uses empirical power system data to identify the power plants that are most likely to have their fuel use and emissions reduced by the addition of wind energy or another zero-carbon solution, and then reports in highly granular detail the impact of that solution on each power plant's emissions. AVERT is available for download at http://epa.gov/statelocalclimate/resources/avert/index.html. AWEA put DOE EIA 2013 state-by-state wind generation data, available at http://www.eia.gov/electricity/monthly/current_year/february2014.pdf, into the AVERT tool. For this analysis, which was intended to calculate where wind power is reducing emissions in physical reality, emissions reductions were counted in the wind-producing region for power purchase contracts that are not known to call for physical delivery of the wind generation, such as those involving renewable energy credit purchases. However, as a policy matter, AWEA is advocating that EPA allocate credit for emissions reductions to the entity purchasing the wind generation and associated environmental attributes, which would result in a different state-by-state distribution. This analysis modeled emissions savings in the receiving region only for power purchase contracts that are known to call for the physical delivery of wind generation from one AVERT region to another, such as those from wind plants in the Northwest to utilities in California and from Upper and Lower Midwest wind plants to utilities in the Southeast. Because the AVERT tool's regions are not perfectly coterminous with actual grid operating areas, particularly in the Southeast and to a lesser extent the Western U.S., to better reflect reality calculated emissions savings in the Southeast were allocated to states with utilities that have wind development or wind purchases with physical delivery of the generation. AVERT does not model Hawaii and Alaska, so those were calculated separately using EIA fuel mix and emissions data. The share of total electric sector CO_2 emissions is calculated from EIA data for 2011, the most recent year for which data is available.

are reducing their emissions due to wind generation, which in interstate power markets are not always the states in which the wind plants are located. Results are listed alphabetically by state name in the first table, and ranked by amount of carbon emission reductions in the second.

According to the results from the AVERT tool, one MWh of wind energy avoids .75 tons, or 1,500 pounds, of carbon dioxide emissions on average. A typical 2 MW wind turbine avoids around 4,000-4,500 tons of carbon emissions annually, equivalent to the annual carbon emissions of more than 700 cars.

Importantly, the AVERT analysis prepared by AWEA also demonstrates that wind energy plays an important role in reducing emissions of SO_2 and NO_x, facilitating compliance with EPA regulations limiting those pollutants. Wind energy currently reduces SO_2 emissions by nearly 347 million pounds per year and NO_x by 214 million pounds per year.

Wind energy reduces emissions because electricity produced by a wind project results in an equivalent decrease in electricity production at another power plant. Due to its low operating costs (and zero fuel cost), grid operators use wind energy to ramp down the output of the online power plants with the highest operating costs, which are typically the least efficient fossil fuel-fired power plants due to their high fuel costs. Wind energy is also occasionally used to reduce the output of hydroelectric dams, which allows the dam to store water that is used later to displace fossil generation.

As discussed in AWEA's most recent annual market report, independent power system operators have also conducted studies that identify the impact of wind generation on system-wide carbon emissions, and have concluded that wind energy displaces 0.48 to 0.81 short tons of carbon dioxide per MWh of wind generated,[8] which is consistent with the results from the AVERT analysis above. Wind's emissions savings vary somewhat by region due to variations in the fossil-fuel generation mix, primarily driven by variations in the share of time that coal versus gas provide marginal generation.

The AWEA report also calculated that in 2013 wind energy saved 36.5 billion gallons of water that would have been consumed at conventional power plants, the equivalent of roughly 116 gallons per person in the U.S. or 276 billion bottles of water, providing critical relief in drought-stricken areas.[9]

[8] AWEA U.S. Wind Industry Annual Market Report for the Year Ending 2013, available at http://www.awea.org/AMR2013
[9] Ibid.

Table 1: State-by-state analysis of wind energy's 2013 emissions reductions using EPA's AVERT tool, ***listed alphabetically by state name***

	CO2 reductions (tons)	Share of 2011 electric sector CO_2 emissions	SO2 reductions (pounds)	NOX reductions (pounds)
Alabama	479,000	0.59%	3,419,000	776,000
Alaska	115,000	3.19%	202,000	1,079,000
Arizona	437,000	0.75%	217,000	548,000
Arkansas	959,000	2.48%	2,528,000	1,843,000
California	8,117,000	16.83%	66,000	6,502,000
Colorado	6,849,000	13.81%	11,413,000	14,384,000
Connecticut	321,000	4.25%	191,000	358,000
Delaware	162,000	3.71%	216,000	145,000
Florida	88,000	0.07%	259,000	115,000
Georgia	1,497,000	1.97%	7,324,000	2,334,000
Hawaii	437,000	5.07%	2,097,000	2,490,000
Idaho	303,000	38.19%	3,000	78,000
Illinois	9,727,000	8.84%	25,665,000	9,438,000
Indiana	2,760,000	2.26%	18,038,000	5,799,000
Iowa	6,496,000	13.70%	27,682,000	14,737,000
Kansas	4,356,000	10.37%	6,666,000	8,126,000
Kentucky	804,000	0.77%	3,651,000	1,040,000
Louisiana	1,705,000	3.23%	8,003,000	2,434,000
Maine	109,000	4.53%	187,000	60,000
Maryland	841,000	3.35%	3,096,000	1,509,000
Massachusetts	635,000	3.88%	1,664,000	564,000
Michigan	1,197,000	1.65%	5,510,000	2,285,000
Minnesota	5,081,000	13.76%	7,023,000	8,640,000
Mississippi	180,000	0.71%	262,000	203,000
Missouri	6,032,000	6.52%	21,689,000	7,729,000
Montana	662,000	3.50%	2,330,000	1,756,000
Nebraska	3,225,000	10.35%	13,314,000	6,467,000
Nevada	651,000	3.91%	1,049,000	1,340,000
New Hampshire	243,000	4.27%	574,000	375,000
New Jersey	532,000	3.01%	224,000	599,000
New Mexico	130,000	0.38%	82,000	374,000
New York	1,500,000	3.87%	2,504,000	2,415,000
North Dakota	2,662,000	7.85%	6,129,000	7,882,000
Ohio	2,477,000	1.99%	16,410,000	4,037,000

Oklahoma	5,996,000	9.98%	18,215,000	15,845,000
Oregon	1,586,000	18.38%	3,214,000	1,712,000
Pennsylvania	2,736,000	2.13%	14,425,000	6,914,000
Rhode Island	150,000	3.77%	6,000	58,000
South Dakota	685,000	18.04%	5,005,000	4,006,000
Tennessee	900,000	1.98%	4,947,000	819,000
Texas	25,413,000	8.86%	68,602,000	29,397,000
Utah	2,818,000	7.08%	2,785,000	10,676,000
Vermont	12,000	66.11%	171	8,000
Virginia	25,000	0.08%	144,000	77,000
Washington	3,727,000	31.52%	1,855,000	9,989,000
West Virginia	1,220,000	1.52%	2,933,000	1,265,000
Wisconsin	5,087,000	9.96%	18,602,000	6,324,000
Wyoming	4,689,000	9.40%	6,561,000	8,873,000
Total	**126,814,000**	**5.11%**	**346,981,000**	**214,422,000**

Table 2: State-by-state analysis of wind energy's 2013 emissions reductions using EPA's AVERT tool, ***ranked by carbon emissions reductions***

State	CO_2 reductions (tons)	Share of 2011 electric sector CO_2 emissions	SO_2 reductions (pounds)	NOX reductions (pounds)
Texas	25,413,000	8.86%	68,602,000	29,397,000
Illinois	9,727,000	8.84%	25,665,000	9,438,000
California	8,117,000	16.83%	66,000	6,502,000
Colorado	6,849,000	13.81%	11,413,000	14,384,000
Iowa	6,496,000	13.70%	27,682,000	14,737,000
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Oklahoma	5,996,000	9.98%	18,215,000	15,845,000
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Wyoming	4,689,000	9.40%	6,561,000	8,873,000
Kansas	4,356,000	10.37%	6,666,000	8,126,000
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Nebraska	3,225,000	10.35%	13,314,000	6,467,000
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Louisiana	1,705,000	3.23%	8,003,000	2,434,000

Oregon	1,586,000	18.38%	3,214,000	1,712,000
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Virginia	25,000	0.08%	144,000	77,000
Vermont	12,000	66.11%	171	8,000
Total	**126,814,000**	**5.11%**	**346,981,000**	**214,422,000**

Wind energy is a widely available electric generating resource.

AWEA's *U.S. Wind Industry Annual Market Report for the Year Ending 2013* finds there are 61,110 megawatts (MW) of wind energy capacity installed in 39 states and Puerto Rico (Figure 1), representing more than 46,000 operational utility-scale wind turbines. There are now 16 states with 1,000 MW or more of installed wind energy capacity.

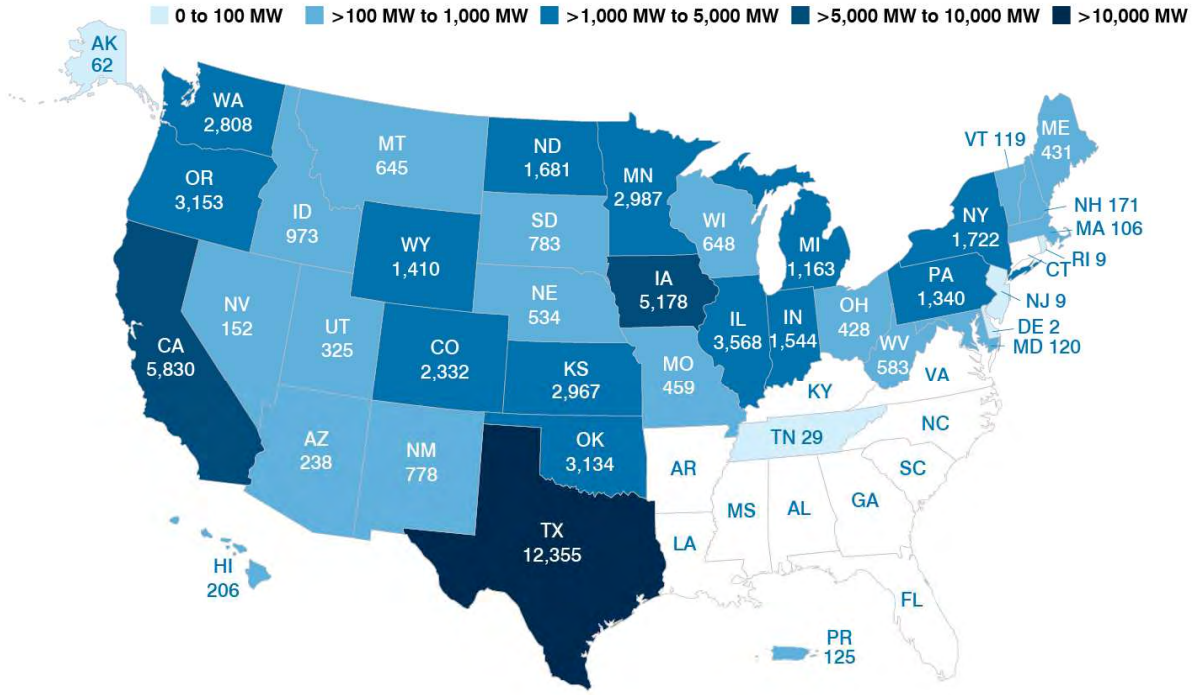

Figure 1: Installed U.S. Wind Energy Capacity in MW, by State through 2013

This represents 5.7 percent of total installed U.S. electric generating capacity. In terms of actual electricity production, wind energy accounted for 4.1 percent of electric generation in 2013 (up from 2.9 percent in 2011 and 3.5 percent in 2012). The existing wind turbine fleet provides the electrical output equivalent to 53 average coal plants, or 14 average nuclear plants.

Over the last five years, wind energy has accounted for 31 percent of all newly installed electric generating capacity, second only to natural gas. In 2012, wind energy was the largest source of all new capacity at 42 percent.

In some regions, such as the Pacific Northwest, Plains states and the Midwest, wind energy has been the primary source of new capacity over the last three years, providing 60 percent or more of all new electric generating capacity. In the Upper Midwest, wind energy provided more than 80 percent of all new generating capacity from 2011-2013.

On an average annual basis, wind energy produces more than 25 percent of the electricity in two states, 12 percent or more in nine states, and five percent or more in 17 (Figure 3).

Even the states not colored in on the two charts above increasingly have opportunities to take advantage of the environmental benefits of wind energy through both projects in-state as well as contracting for wind energy from out-of-state.

Wind energy technology is rapidly improving, mostly through the use of taller towers and longer blades that allow access to higher wind speeds and make lower-wind-speed sites more economic. As a result, wind project developers

Georgia and Louisiana, according to press reports. Moreover, utilities in Tennessee, Arkansas, Georgia, Alabama, and Louisiana have already signed power purchase contracts to buy electricity from wind energy facilities in other states, demonstrating that wind energy is a widely available compliance option nationwide.

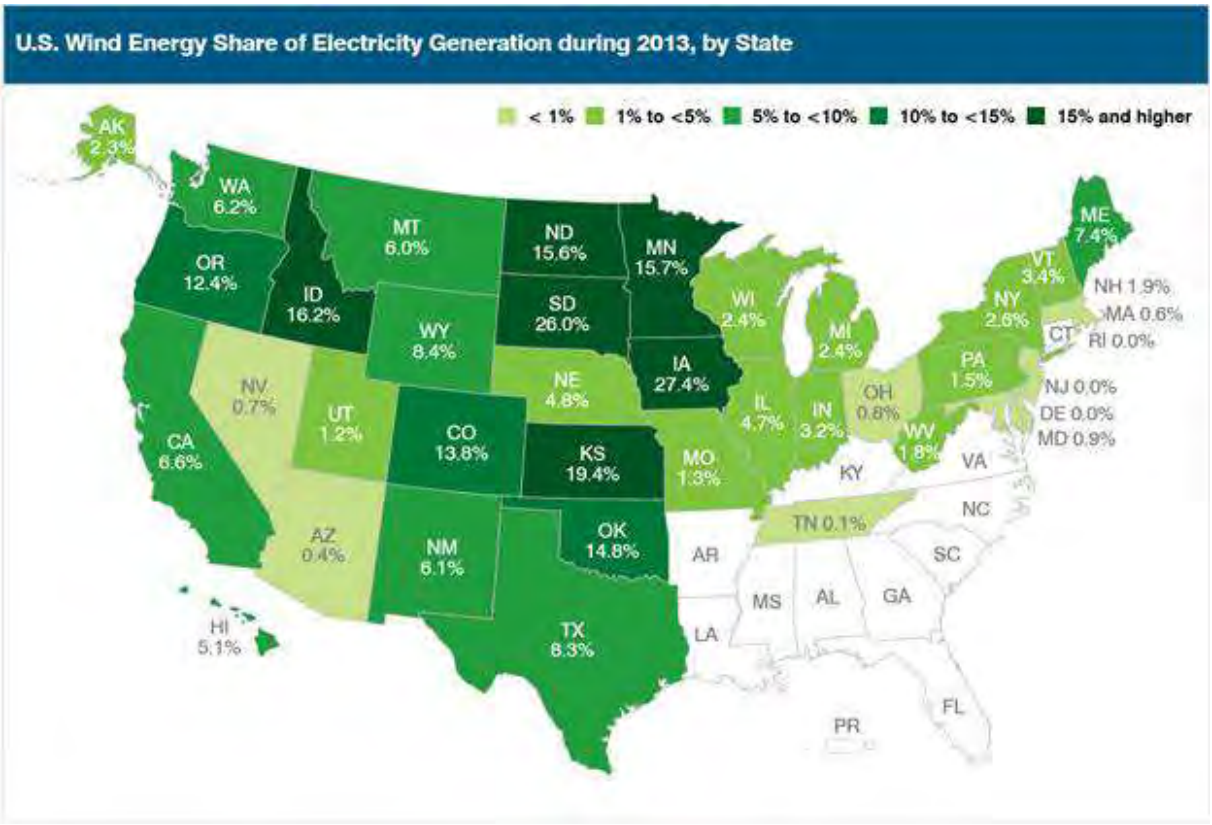

Figure 2: Percentage share of electricity generation by Wind during 2013, by State

are now exploring opportunities in states where wind energy was not previously viable, such as much of the Southeast. In addition to the 39 states with existing installed wind energy capacity, wind energy project developers have publicly acknowledged the pursuit of wind projects in Kentucky, Virginia, North Carolina, Florida, and Alabama, with initial prospecting in

Wind energy is affordable.

Wind energy's costs are declining dramatically. Lazard, a widely-respected financial advisory and asset management firm reported[10] (Figure 3) in 2013 that wind energy is second only to natural gas combined cycle power plants for being the most affordable source of new electric generation, even without considering incentives. This analysis included operating, maintenance and transmission costs.

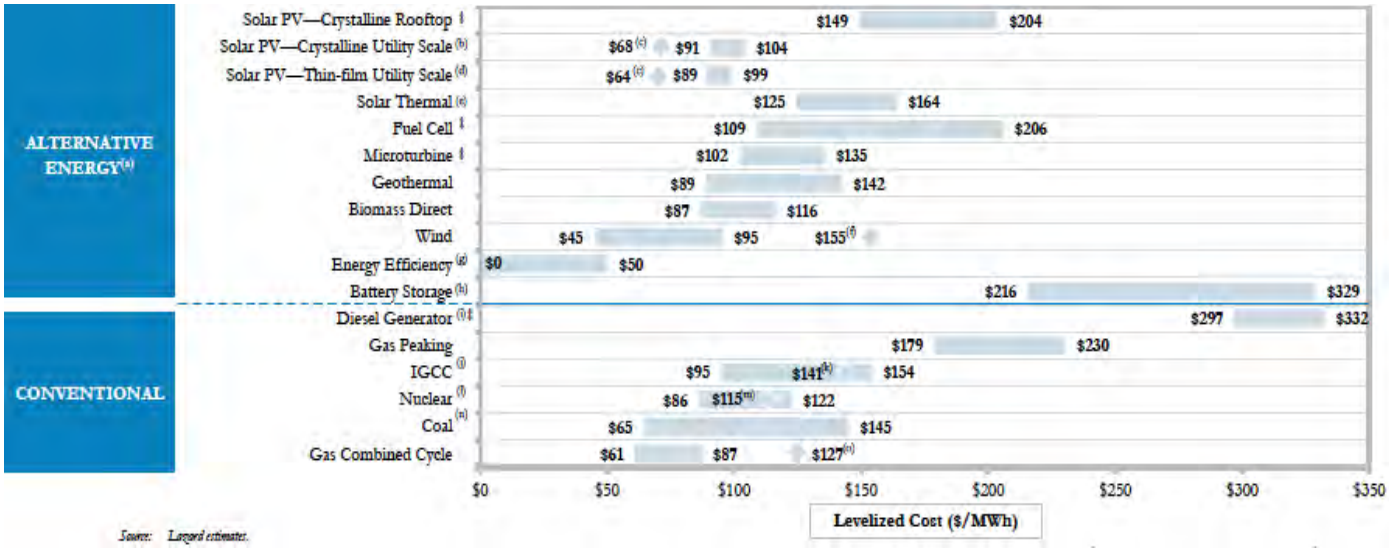

Figure 3: Levelized cost of energy (LCOE) analysis from Lazard

The U.S. Energy Information Administration projects similar results for 2019, with wind energy being one of the most affordable options second only to combined cycle natural gas.[11] Wind energy costs declined dramatically, more than 7 percent, since last year's EIA assessment.

Other DOE data confirm the marked decline in wind energy's costs, with data based on real-world contracts for wind energy showing even lower costs. DOE's annual wind market report[12] indicates the price of wind energy power purchase agreements declined 43 percent from 2009-2012 to a low of $40/MWh in 2012. Those declines appear to have continued over the last year based on recent public announcements of very low-priced wind power purchase agreements. For example, in wind-rich areas, some wind power purchase agreements have been recorded in the $20-30/MWh range.

A May 2013 report[13] by Synapse Energy Economics found that doubling the use of wind energy in the Mid-Atlantic and Great Lakes states would save consumers $6.9 billion per year on net, after accounting for all wind and transmission investment costs.

[10] Lazard's Levelized Cost of Energy Analysis, image available at http://i0.wp.com/cleantechnica.com/files/2013/09/Screen-shot-2013-09-11-at-1.50.34-PM.png. Wind's range of costs in the image are primarily due to regional variations in wind plant capacity factor and installed costs for wind. The dot at $155/MWh in the image represents offshore wind.

[11] http://www.eia.gov/forecasts/aeo/electricity_generation.cfm , Table 1

[12] DOE 2012 Wind Technologies Market Report, available at: http://emp.lbl.gov/sites/all/files/lbnl-6356e.pdf

[13] Synapse Energy Economics, *The Net Benefit of Increased Wind Power in PJM,* by Bob Fagan, Patrick Luckow, Dr. David White, and Rachel Wilson (Cambridge, MA, 2013), available at: http://www.synapse-energy.com/Downloads/SynapseReport.2013-05.EFC.Increased-Wind-Power-in-PJM.12-062.pdf

More than a dozen other studies confirm the finding that wind energy drives electricity prices down, which is of course good for consumers.[14]

In addition to its current affordability, contracted wind energy is guaranteed to remain affordable tomorrow because it offers the stability of a long-term fixed energy price for 15-25 years. This is in contrast to the volatile prices that can characterize non-renewable fuels.[15] Wind energy keeps energy prices low much like a fixed rate mortgage protects homeowners from interest rate spikes. As the Lawrence Berkeley National Lab reported, wind energy acts as a hedge to protect consumers even in an environment in which gas prices are below historic averages.[16]

Newly released Department of Energy data[17] show that energy prices in states that use the most wind energy have on average trended lower than in states that use less wind energy. The eleven states that produce more than seven percent of their electricity from wind energy have seen their electricity prices fall by a demand-weighted average of 0.37 percent over the last 5 years, while all other states have seen their electricity prices increase by 7.79 percent over the same time period. Between the end of 2008 and the end of 2013, these eleven top wind states more than doubled their operating wind power, increasing their wind capacity by 116 percent.

Wind energy's emissions reductions are easily quantified and verified.

Wind energy's emissions reductions are readily quantifiable and verifiable, making wind energy an attractive solution for states to comply with 111(d). All utility-scale wind projects have revenue-grade metering equipment that measures the amount of wind energy production. Among other reasons, such equipment and verification is necessary to ensure compliance with power purchase contract generation requirements and for

[14] See page 4 at http://awea.files.cms-plus.com/AWEA%20White%20Paper-Consumer%20Benefits%20final.pdf

[15] The following quotes provide examples of utilities acknowledging the affordability of wind energy: "Wind Prices are extremely competitive right now, offering lower costs than other possible resources, like natural gas plants. These projects offer a great hedge against rising and often volatile fuel prices." David Sparby, president & CEO of Xcel Energy's Northern States Power announcing 600 MW of new wind power contracts on July 16, 2013, available http://www.greentechmedia.com/articles/read/wind-power-said-to-beat-natural-gas-in-midwest; an AEP subsidiary in Oklahoma tripled the amount of wind energy it planned to buy last year because "extraordinary pricing opportunities that will lower costs for PSO customers by an estimated $53 million in the first year of the contracts…annual savings are expected to grow each year over the lives of the contracts." available at: http://www.nawindpower.com/e107_plugins/content/content.php?content.12588; John Kelley, Alabama Power's Director of Forecasting and Resource Planning stated: "These agreements [referring to contracts to purchase wind power] are good for our customers for one very basic reason, and that is, they save our customers money." available at: http://www.renewableenergyworld.com/rea/news/article/2012/10/alabama-power-wants-more-affordable-wind-power; MidAmerican Energy's 2013 press release after the Iowa Utilities Board approved the addition of 1,050 MW of wind generation in Iowa "The expansion is planned to be built at no net cost to the company's customers and will help stabilize electric rates over the long term by providing a rate reduction totaling $10 million per year by 2017, commencing with a $3.3 million reduction in 2015." Available at: http://www.midamericanenergy.com/wind_news.aspx

[16] Ernest Orlando Lawrence Berkeley National Laboratory, *Revisiting the Long-Term Hedge Value of Wind Power in an Era of Low Natural Gas Prices* 21 (March 2013), available at http://emp.lbl.gov/sites/all/files/lbnl-6103e.pdf (". . . even in today's low gas price environment, and with the promise of shale gas having driven down future gas price expectations – wind power can still provide protection against many of the higher-priced natural gas scenarios . . .").

[17] U.S. Energy Information Administration, Electric Power Monthly with Data for November 2013 (January 2014), available at: http://www.eia.gov/electricity/monthly/pdf/epm.pdf. Additional analysis available in the AWEA report *Wind Power's Consumer Benefits* available at: http://awea.files.cms-plus.com/AWEA%20White%20Paper-Consumer%20Benefits%20final.pdf

purposes of claiming the federal production tax credit (PTC), which is based on electricity actually generated, on tax returns.

In addition, rigorous accounting mechanisms for renewable energy credits are in wide use in 29 states and the District of Columbia for compliance with state renewable portfolio standard requirements in those states, and accounting mechanisms are in place nationwide for verifying renewable energy production to satisfy voluntary purchases of such credits. These well-established accounting mechanisms could be readily adopted for compliance with section 111(d) to ensure that renewable energy production is not double-counted and can be precisely and rigorously quantified.

Several tools, such as marginal emissions calculations[18] and power system modeling, allow carbon emissions reductions to be calculated based on the measured wind energy production. EPA's AVERT, used for the wind emissions savings analysis above, is a free and easy-to-use option for calculating wind energy's pollution reductions.[19]

The cycling of other generation has a negligible impact on wind's emissions savings.

While other generation may on occasion need to ramp up or down to accommodate the variability of wind energy (plus the variability of other far larger sources of variability on the power system like electricity demand and the sudden failure of large conventional generators), two recent studies from different regions in the U.S. document that such cycling has virtually no negative effect on the emissions reductions from wind energy.

A peer-reviewed analysis by a Department of Energy lab found that wind energy produces 99.8 percent of the carbon emissions savings expected of a zero-emissions resource.[20] The study examined real-world hourly emissions from every power plant in the western U.S. and analyzed the impact wind energy has on the efficiency of other power plants by causing them to change their output more frequently. The study found that for a scenario with wind and solar providing 33 percent of electricity on the Western U.S. power system, one MWh of wind energy saves more than 1,190 pounds of carbon pollution on average, with those savings reduced by only 0.2 percent, or 2.4 pounds, as a result of increased cycling of fossil-fired power plants.

[18] Marginal generation and emissions data track which power plant or power plants are economically "on the margin" in each operating hour, and thus which generating units would have been dispatched down had demand been 1 MW lower or an additional 1 MW of low-cost supply (such as from wind) been available, allowing one to calculate the marginal emissions savings based on the heat or emissions rate for those marginal units. When combined with an hourly wind output profile for the region, that allows one to calculate wind's total emissions savings with a very high degree of accuracy. Some Independent System Operators (ISOs) and utilities already calculate and publicly release data on marginal fuel mixes and emissions, and other utilities should already have the data necessary to conduct such a calculation. For example, see http://www.iso-ne.com/genrtion_resrcs/reports/emission/.

[19] Available at: http://epa.gov/statelocalclimate/resources/avert/index.html

[20] National Renewable Energy Lab Western Wind and Solar Integration Study, Phase 2 Results, available at: http://www.nrel.gov/docs/fy13osti/55588.pdf; all WWSIS documents available at: http://www.nrel.gov/electricity/transmission/western_wind.html

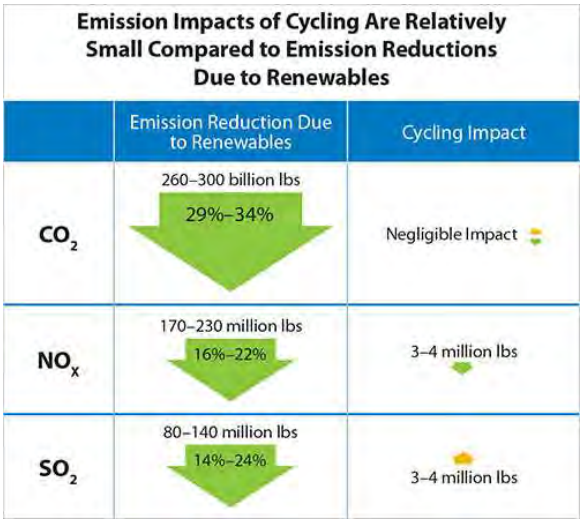

Figure 4: National Renewable Energy Lab, Western Wind and Solar Integration Study Phase II results

This finding was confirmed by PJM's March 2014 renewable integration study, which found scenarios with large amounts of wind energy still yielded the expected emissions reductions after cycling impacts were taken into account.[21]

DOE data also show that states that have ramped up their use of wind energy the most have seen the efficiency of their fossil-fired power plants hold up as well or better than states that use the least wind energy.[22]

As explained in the next section, the impact of cycling is virtually non-existent because wind energy only incrementally adds to existing power system variability and flexible reserve needs..

[21] See http://www.pjm.com/~/media/committees-groups/task-forces/irtf/postings/pjm-pris-task-3a-part-g-plant-cycling-and-emissions.ashx at page 91. The differences in CO_2 emissions savings among the study's scenarios are driven by the fact that, due to their different output profiles, onshore wind tends to offset more carbon-intensive coal generation while other renewable resources, such as offshore wind and solar, tend to offset more gas generation. The high onshore wind cases all produce emissions reductions that are almost directly proportional to the quantity of fossil MWh displaced, indicating the impact of cycling is minimal.

[22] Goggin, M., 2013, "Wind energy's emissions reductions: A statistical analysis," available at http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6672865&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel7%2F6657332%2F6672065%2F06672865.pdf%3Farnumber%3D6672865

Large amounts of wind energy can be reliably integrated onto the power system

Grid operators are now reliably accommodating very large quantities of renewable energy in the U.S. and Europe. As explained above, wind energy produces more than 25 percent of the electricity in two states, 12 percent or more in nine states, and five percent or more in 17 states on an annual basis. In certain hours, wind has

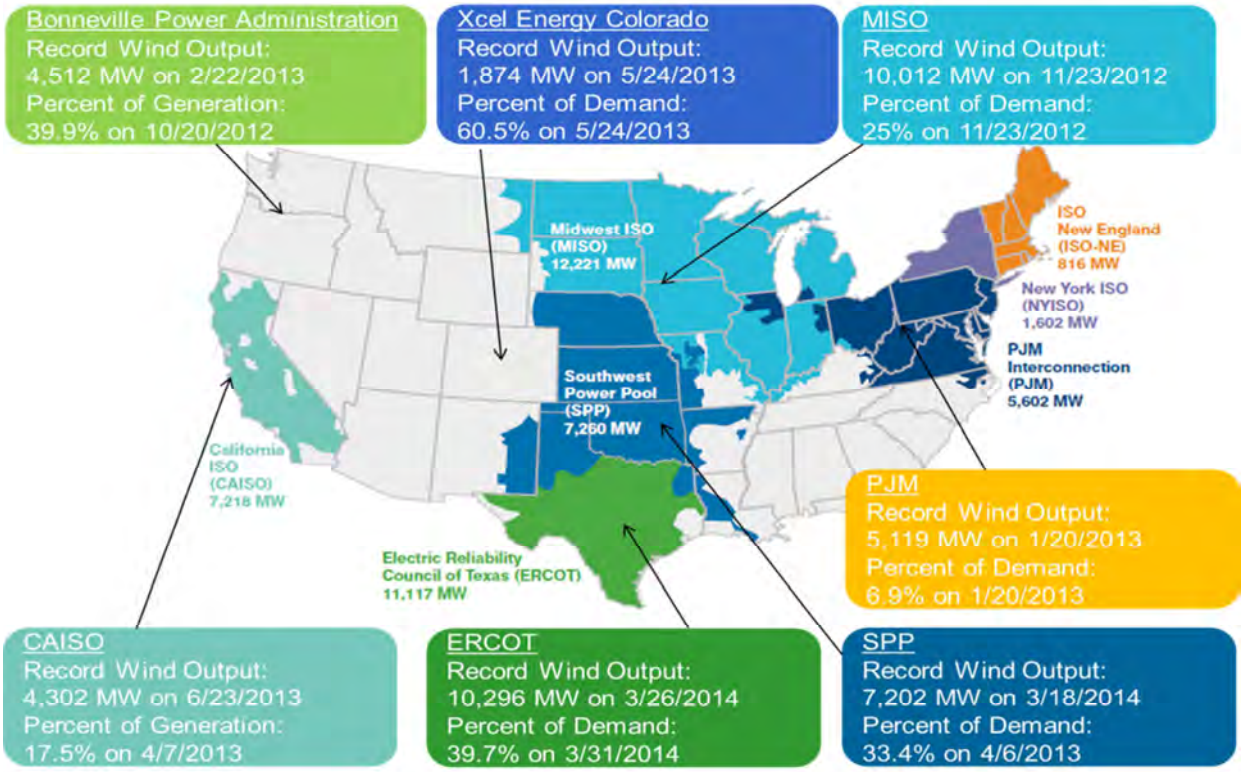

Figure 5: Wind energy integration records set in the U.S. 2012-2014; Source: AWEA Annual Market Report for the Year Ending 2013

supplied more than 60 percent of the electricity on the main utility system in Colorado without any reliability problems, and other grid operators have also reliably integrated very large amounts of wind energy, as indicated in Figure 6.

Grid operators in Texas have integrated more than 10,000 MW of wind energy with only very small increases in their need for flexible reserves, with the need for fast-acting flexible reserves increasing by less than 100 MW.[23] The Midcontinent Independent System Operator (MISO) has also stated that the impact of wind power has had on its need for flexible reserves, used to accommodate variability in electricity supply and demand, has been "little to none."[24]

The March 2014 renewable integration study[25] by the PJM grid operator confirms that wind energy only minimally contributes to total power system variability, with the addition of 28,000 MW of wind capacity in the 14 percent renewable energy scenario, causing an increase in operating reserve needs of only 340 MW. This is about 1/10 of the 3,350 MW of the operating reserves PJM needs at all times to maintain

[23] Available at: http://variablegen.org/wp-content/uploads/2012/12/Maggio-Reserve_Calculation_Methodology_Discussion.pdf
[24] Available at: http://variablegen.org/wp-content/uploads/2012/12/Navid-Reserve_Calculation.pdf
[25] Renewable Integration Study for PJM, available at: http://www.pjm.com/~/media/committees-groups/task-forces/irtf/postings/pjm-pris-final-project-review.ashx, at page 111

reliability in case a large conventional power plant abruptly fails, and less than one-third the amount of reserves necessary to deal with variability in electricity demand. Current data indicate the largest hourly changes in electricity demand are 10 times larger than the largest hourly changes in wind energy output for PJM.[26] PJM's integration study concluded that the "PJM system, with adequate transmission and ancillary services in the form of Regulation, will not have any significant issue absorbing the higher levels of renewable energy penetration considered in the study."[27]

Dozens of in-depth wind integration studies[28] confirm that far larger amounts of wind energy can be added to the power system without harming reliability. How is this possible when the wind doesn't blow all the time?

Every day, grid operators constantly accommodate variability in electricity demand and supply by increasing and decreasing the output of flexible generators – power plants like hydroelectric dams or natural gas plants can rapidly change their level of generation. Thus, the water kept behind a dam or the natural gas held in a pipeline may be thought of as a form of energy storage, with operators using this energy when it is needed and "storing" it when it is not.

Grid operators have always kept large quantities of fast-acting generation in reserve to respond to abrupt failures at large conventional power plants, a challenge and cost that is far greater than accommodating any incremental variability added by the gradual and predictable changes in the aggregate output of a wind fleet. Grid operators use these same flexible resources to accommodate any incremental variability introduced by wind energy that is not canceled out by other changes in electricity supply or demand. Wind energy's impact on total power system variability and uncertainty, and, in turn, its impact on reserve needs, is greatly reduced as most changes in wind output are offset by other changes in supply or demand.

In addition, wind plant technology has matured significantly over the last decade so that modern wind turbines provide equivalent or better capabilities[29] for supporting power system reliability needs as conventional power plants in almost every category. Recent analysis by WECC, the entity responsible for power system reliability in the Western U.S., found that in a scenario with very high renewable penetration across the West, "the system results did not identify any adverse impacts due to the lower system inertia or differently stressed paths due to the higher penetration of variable generation resources."[30] Analysis conducted for the California grid operator identified no major concerns for frequency response in a transition to a high-renewable future, finding that "None of the credible conditions examined, even cases with significantly high levels of wind and solar generation (up to 50% penetration in California), resulted in under-frequency load shedding (ULFS) or other stability problems."[31] This occurs in part because adding wind generation causes conventional power plants to have their output reduced, which provides them with more

[26] http://www.pjm.com/~/media/committees-groups/task-forces/irtf/20130417/20130417-item-05-wind-report.ashx, and http://www.pjm.com/markets-and-operations/energy/real-time/loadhryr.aspx
[27] http://www.pjm.com/~/media/committees-groups/committees/mic/20140303/20140303-pjm-pris-final-project-review.ashx, page 12
[28] For the full list, see: http://variablegen.org/resources/
[29] See this NERC report: http://www.nerc.com/docs/pc/ivgtf/IVGTF_Report_041609.pdf, at page 22
[30] Available at http://www.wecc.biz/committees/StandingCommittees/PCC/RS/RPEWG%20-%20RS%20Meetings8-21-13/Lists/Minutes/1/VGSStudy7-15-13.doc
[31] Available at http://www.caiso.com/Documents/Report-FrequencyResponseStudy.pdf

range to increase their output and provide frequency response.[32]

In addition, new techniques employing wind plants' sophisticated controls and power electronics enable wind plants themselves to provide fast-acting frequency response. The National Renewable Energy Laboratory (NREL) recently released an in-depth analysis that concluded "wind power can act in an equal or superior manner to conventional generation when providing active power control, supporting the system frequency response and improving reliability."[33] The report further documented how major utilities like Xcel Energy are using this capability of wind plants in some hours to provide all of the frequency response and regulation needed to maintain power system reliability, which has enabled Xcel's Colorado power system to at times reliably obtain more than 60 percent of its electricity from wind energy.

Going forward, the emissions reduction potential from wind energy is even greater.

More than a dozen utility and independent grid operator studies have found wind can reliably provide an even larger share of our electricity, producing even larger emissions reductions. An NREL study for the Eastern U.S.[34] found that obtaining 20 percent of electricity from wind energy cut power sector carbon emissions by 25 percent, and 30 percent wind cut carbon emissions by 37 percent, relative to the baseline generation mix.

The Department of Energy found that a scenario of 20 percent wind energy by 2030[35] was technically and economically feasible. The U.S. is currently ahead of schedule in reaching 20 percent wind energy by 2030. This DOE study found that the 20 percent wind scenario would avoid 825 million tons of CO_2 annually by 2030, cutting expected electric sector emissions by 20-25 percent, the equivalent of taking 140 million vehicles off the road. This 2008 DOE study is being updated and is expected to be released later in 2014.

Real-world experience in European countries confirms that wind energy is a reliable and highly effective tool for reducing carbon dioxide emissions. Denmark, Germany, Ireland, Portugal, and Spain lead the world in obtaining the largest share of their electricity from wind energy, and all have seen drastic declines in the carbon intensities of their electric sectors. As indicated in the table below[36], there is a very strong relationship between growth in wind generation and a decline in carbon intensity. Interestingly, Germany would have seen a far larger decline in carbon intensity had it not, for unrelated reasons, reduced the share of electricity it obtains from nuclear energy from 29.6 percent in 2001 to 17.7 percent in 2011.

Country	Wind % '01	Wind % '11	Share growth	CO_2/MWh % change
Denmark	11.9%	29.1%	17.2%	-28.9%
Germany	1.9%	8.5%	6.6%	-12.3%
Ireland	1.4%	16.6%	15.2%	-36.1%
Portugal	0.6%	17.9%	17.4%	-32.4%
Spain	3.0%	15.2%	12.2%	-23.8%
OECD Europe	**0.8%**	**5.3%**	**4.4%**	**-11.0%**

[32] http://web.mit.edu/windenergy/windweek/Presentations/GE%20Impact%20of%20Frequency%20Responsive%20Wind%20Plant%20Controls%20Pres%20and%20Paper.pdf
[33] Available at http://www.nrel.gov/news/press/2014/7301.html
[34] National Renewable Energy Lab Eastern Wind Integration Study, available at: http://www.nrel.gov/electricity/transmission/eastern_renewable.html

[35] 20% Wind Energy by 2030: Increasing Wind Energy's Contributions to U.S. Electricity Supply, U.S. Department of Energy, available at: http://www.nrel.gov/docs/fy08osti/41869.pdf
[36] The data to create this chart came from International Energy Agency statistics through 2011, the most recent year for which data on CO_2 per MWh are available. IEA statistics are available at: http://www.iea.org/statistics/

Wind energy is scalable and rapidly deployable, and thus ideal as an emissions reduction tool.

Wind plants offer a rapidly deployable solution for reducing emissions of carbon dioxide and other pollutants. Wind developers already have a large backlog of wind projects in the development pipeline, and it is typically possible to build a wind project in a little over a year, far faster than many other low- or zero-carbon solutions.

Since the end of 2005, the U.S. wind energy industry has doubled its installed capacity, on average, every 36 months. Over the last decade, the industry has gone from a low mark of installing 396 MW in 2004 to a high of more than 13,000 MW in 2012, and there are currently more wind projects under construction in the U.S. than at any point in history. U.S. wind energy's five year average annual growth rate is 19.5 percent from 2009-2013. The previously mentioned DOE 20 percent wind report found that with existing technology, the industry can ramp up to sustained deployment of around 16,000 MW of newly installed wind capacity per year.

In 2003, wind energy generated only 11 million MWh, or 0.3 percent of the generation mix. By 2008, wind energy generated 55 million MWh, or 1.3 percent of the mix. In 2013, wind energy generated 167 million MWh, or 4.1 percent of total generation.[37]

[37] The statistics in this section come for the AWEA annual market report for the year ending 2013.

Wind Power for a Cleaner America

Reducing Global Warming Pollution, Cutting Air Pollution and Saving Water

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November 2012

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Executive Summary

Coal- and natural gas-fired power plants pollute our air, are major contributors to global warming, and consume vast amounts of water—harming our rivers and lakes and leaving less water for other uses. Wind energy has none of these problems. It produces no air pollution, makes no contribution to global warming, and uses no water.

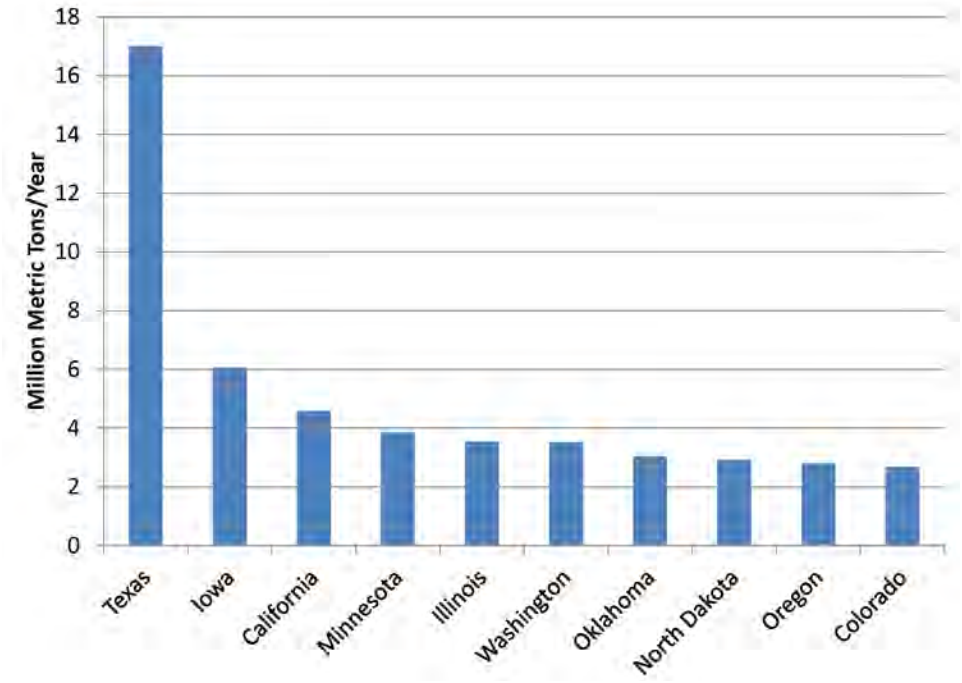
America has more than doubled its use of wind power since the beginning of 2008 and we are starting to reap the environmental rewards. **Wind energy now displaces about 68 million metric tons of global warming pollution each year—as much as is produced by 13 million cars. And wind energy now saves more than enough water nationwide to meet the needs of a city the size of Boston.**

There is still plenty of room for growth in wind energy. But the pending expiration of the production tax credit threatens the future expansion of wind power. To protect the environment, federal and state governments should continue and expand policies that support wind energy.

Burning fossil fuels for electricity generation has widespread environmental and public health consequences.

- Combustion of coal and natural gas exacerbates global warming, the effects of which are already being felt across the nation. The average annual temperature in the U.S. has already risen 2° F in the past 50 years, and the number of heat waves has increased. Extreme rain and snowfall events have become 30 percent more common. Sea

Figure ES-1. Top 10 States for Global Warming Emission Reductions from Wind Energy in 2011



level has risen eight inches or more along parts of our coasts.

- Coal- and natural gas-fired power plants require vast amounts of water for cooling, reducing the amount of water available for irrigation, wildlife, recreation or domestic use, now and in the future. More water is withdrawn from U.S. lakes, rivers, streams and aquifers for the purpose of cooling power plants than for any other purpose.
- Air pollution from power plants threatens the health of millions of Americans.

Wind energy avoids about 68 million metric tons of global warming pollution annually—equivalent to taking 13 million of today's passenger vehicles off the road—and saves more than enough water to supply the annual water needs of a city the size of Boston. Wind energy also avoids 137,000 tons of nitrogen oxide emissions and 91,000 tons of sulfur dioxide emissions, important contributors to ozone smog and soot pollution.

- Texas, Iowa and California lead the nation in wind energy capacity, delivering the greatest reductions in global warming pollution, water consumption, and health-threatening air pollution. (See Figure ES-1 and appendices.)

If construction of new wind energy projects continues from 2013 to 2016 at a pace comparable to that of recent years, the United States could reduce global warming pollution by an additional 56 million metric tons in 2016—equivalent to the amount produced by 11 million passenger vehicles. These projects would also save enough water to meet the annual water

needs of 600,000 people, and reduce air pollution by an additional 108,000 tons of nitrogen oxides and 79,000 tons of sulfur dioxide.

America has abundant wind energy potential. The U.S. Department of Energy estimates that 20 percent of the nation's electricity could be supplied by wind power in 2030, up from 3 percent in 2011. To achieve that level of generation, construction of new generating capacity would need continue at levels comparable to that of recent years.

Wind energy's success in reducing air pollution and saving water will continue to grow if policies such as tax incentives and renewable electricity standards are continued and expanded at the state and federal level:

- **The production tax credit.** The federal renewable electricity production tax credit (PTC) has been one of the most important tools to help grow the wind industry in the United States, but it is set to expire at the end of 2012. The loss of the tax credit could cause new construction to drop by 75 percent—and allow global warming pollution and water consumption to continue unabated.
- **The offshore wind investment tax credit.** The offshore wind investment tax credit (ITC) is designed to address the longer timelines for development and construction of offshore wind energy facilities. It covers up to 30 percent of the cost of new wind investments and grants offshore wind developers eligibility for the credit at the point that construction begins. The offshore wind ITC also expires on December 31, 2012.
- **Strong renewable electricity standards.** A strong renewable electricity standard (RES) helps support wind energy development by requiring utilities to obtain a percentage of the electricity they provide to consumers from renewable sources. These standards help ensure that wind energy producers have a market for the electricity they generate and protect consumers from the sharp swings in energy prices that accompany over-reliance on fossil fuels. Today, 29 states have renewable electricity standards—other states and the federal government should follow their lead.
- **Tax policies for renewable energy.** Changes to the federal tax code could make more private investment available to wind energy nationwide by expanding two tax provisions that have benefited investors in non-renewable sources for decades.
- **Transmission policies.** Upgrading and expanding existing electricity transmission infrastructure can connect areas with high electricity demand to areas of high wind energy output. Transmission upgrades should occur only where clearly necessary and where environmental impacts will be minimal.

Introduction

There is a clean energy revolution happening in America.

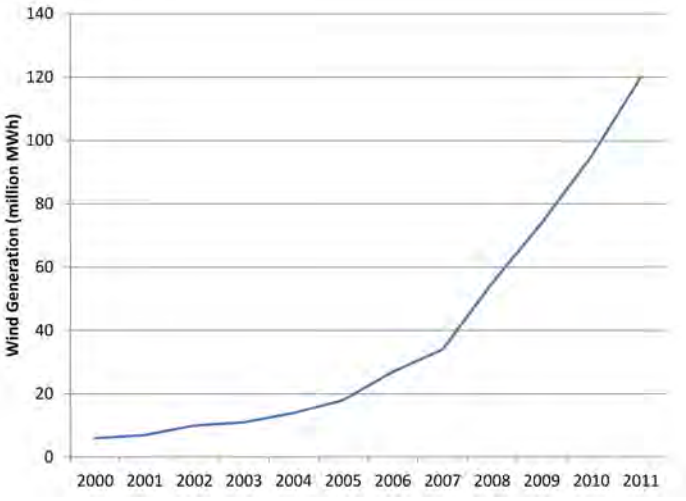
From the Pacific Coast to the Great Plains to the Northeast, renewable energy is on the rise, producing an increasing share of our electricity with minimal impact on the environment.

Consider wind energy. Just a decade ago, wind power was a trivial part of America's energy mix. Today, wind power accounts for 3 percent of our electricity. From 2006 to 2011 the amount of electricity America gets from wind power has quadrupled.

That remarkable progress is generating real environmental results. Wind energy is reducing demand for electricity from fossil fuels such as coal and natural gas—curbing emissions that cause global warming and harm our health while minimizing the use of water for cooling.

The boom in renewable energy, however, is no accident. It has taken the leadership of far-sighted state and federal policy-makers to create the conditions under which wind energy and other forms of renewable energy can thrive. With the environmental and economic benefits of wind energy becoming ever more apparent, now is the time for our leaders to renew their commitment to key clean energy policies.

Figure 1. Growth in Electricity Generated from Wind Power[1]



Power Plants Damage the Environment

Burning coal and natural gas to generate electricity damages the environment by contributing to global warming, consuming vast quantities of water, and creating health-threatening air pollution.

Power Plants Help Fuel Global Warming

Power plants produce 40 percent of America's energy-related global warming pollution.[2] (See Figure 2.) While coal-fired power plants emit twice as much carbon dioxide as natural gas plants per unit of electricity, natural gas is far from a clean fuel.[3] Leaks during the extraction, storage and transportation of natural gas can release methane, a particularly potent global warming pollutant.[4] Recent studies suggest that those leaks may make natural gas—especially gas produced through hydraulic fracturing—nearly as damaging to the climate as coal.[5]

The United States is already feeling the impacts of global warming. In the last 50 years the U.S. average annual temperature has risen 2° F and experts project that it will continue rising. By 2100, the United States Global Change Research Program (USGCRP) anticipates a temperature increase of 4 to 11° F, depending on the scale of greenhouse gas emissions.[7]

Global warming has been linked to an increase in the frequency of intense rain and snowstorms across the United States. Extreme downpours now happen 30 percent more often nationwide than in 1948, and the largest annual storms now produce 10 percent more precipitation on average.[8] Meanwhile, the number of heat waves in the United States has increased since 1960 while the projected time between prolonged dry spells has become shorter.[9]

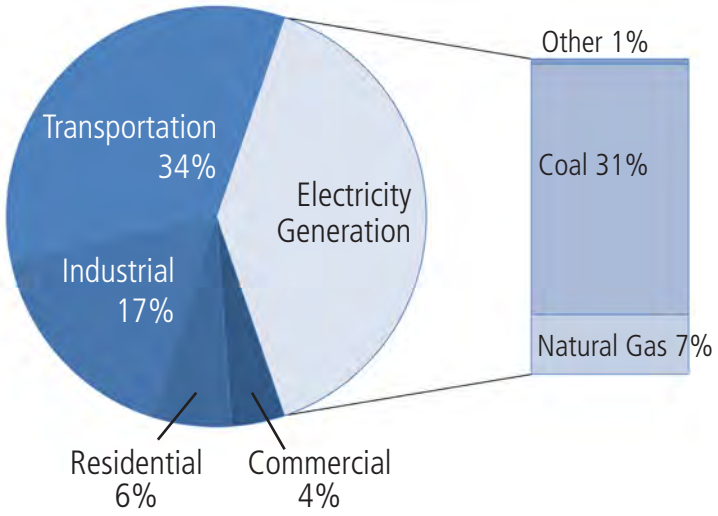
Sea levels have risen eight inches along some parts of the U.S. coastline in the past 50 years. Rising seas erode shorelines—putting homes, businesses and infrastructure at risk—and can cause saltwater intrusion into coastal fresh water aquifers, leaving some unusable without desalination.[10]

These and other impacts are expected to become more pronounced in the decades to come. Public health could suffer as heat waves become more frequent, longer lasting, and more intense, causing more heat-related deaths. Air quality will also be compromised as higher temperatures contribute to ozone "smog" formation, causing more illness, missed days of work and school, and hospitalizations.[11]

Rising temperatures may cause larger and more frequent forest fires, push some tree species northward and to higher altitudes, and eliminate other species altogether. In the oceans, warmer temperatures will cause shifts in marine species. Lobster catches in the southern part of the Northeast have already declined sharply due to the rise of a temperature-sensitive bacterial shell disease.[12]

Science tells us that we need to reduce our emissions of global warming pollution immediately and dramatically if we are to prevent the worst impacts of global warming.[13] Replacing fossil fuel-fired power plants with those using clean renewable energy is an important piece of any strategy to reduce global warming pollution.

Figure 2. Energy-Related Carbon Dioxide Emissions by Sector in the U.S., 2011, with Electricity Generation Broken Down by Fuel[6]



Power Plants Consume Lots of Water

More water is withdrawn from U.S. lakes, rivers, streams and aquifers for the purpose of cooling power plants than for any other purpose.[14] Power plants draw water from local sources for cooling, then either release the heated water back into waterways or evaporate it in a cooling tower. Consumption of water by power plants threatens critical ecosystems and reduces the amount available for human use and the protection of wildlife.

Power plants' thirst for water adds to the strain on local water supplies at times and in places where water is scarce. In Georgia in 2007, for example, a severe drought caused fierce competition for water from Lake Lanier, a major drinking water reservoir for Atlanta.[15] Georgia residents needed the water in the lake for domestic use, while a coal-fired

power plant in Florida wanted more water released for cooling. At the same time, two endangered species of mussels downstream also required an adequate water flow.

Power plants in arid regions also contribute to the long-term drawdown of critical groundwater supplies. In the Southwest and California, approximately one-third to two-thirds of the water consumed by power plants comes from groundwater.[16] For many of these regions, water withdrawn for electricity generation—combined with water pumped for other purposes—has been causing water levels in aquifers to drop, threatening the long-term viability of those aquifers.

By lowering water levels in rivers and streams and raising water temperatures, power plants also threaten aquatic ecosystems. Water discharged from a power plant can be 17 degrees hotter than it was when it was withdrawn for cooling.[17] Discharge temperatures may exceed 90 degrees. This hotter water affects the health and viability of the plants and animals living in the receiving waterway. In addition to the threat posed by heat stress, warmer water holds less dissolved oxygen. For example, fish in Lake Norman, in North Carolina, have been killed by hot water discharged from the cooling systems of two power plants and low dissolved oxygen levels caused in part by the heat.[18] Low water levels due to drought and power plant withdrawals compound the problem, allowing water temperatures to rise faster and higher.

Long before fuel is burned in a power plant, the mining and extraction of coal and natural gas hurts water supplies. Natural gas extraction through hydraulic fracturing involves mixing large volumes of water with chemicals and sand. Most of the water is pumped deep underground and is lost to the water cycle forever. The little that returns to the surface usually is too polluted for any use other than more mining or fracking. Coal production, too, destroys water supplies through pollution and destruction of waterways.

When Water Runs Low, Less Electricity May Be Produced

The dependence of most coal and natural gas-fired power plants on water supplies is not just an environmental problem—it can also threaten the stability of the electric grid. Without sufficient access to cool water, power plants have to reduce their output, often at the times when their electricity is in highest demand.

In 2007, drought and high water temperatures forced Duke Energy to curtail generation at two coal-fired power plants in North Carolina.[19] During the Texas drought in 2011, the cooling water supply serving the Martin Creek Power Plant dropped so much that water had to be piped in from a nearby river to cool the plant.[20] Officials in Texas warned that if the 2011 drought continued unabated into 2012, more power plants would be affected.[21] Thus, during hot summer months—when demand for power to run air conditioners is at its highest—power plants dependent on water for cooling can be forced offline.

Power Plants Create Air Pollution

Coal- and natural gas-fired power plants also produce pollution that contributes to ozone smog, particulate matter and acid rain. This pollution hurts public health and ecosystems.

When inhaled, ozone quickly reacts with airway tissues and produces inflammation similar to sunburn on the inside of the lungs. This inflammation makes lung tissues less elastic, more sensitive to allergens, and less able to ward off infections.[22] Minor exposure to ozone can cause coughing, wheezing and throat irritation. Constant exposure to ozone over time can permanently damage lung tissues, decrease the ability to breathe normally, and exacerbate or potentially even cause chronic diseases like asthma.[23] Children, adults who are active outdoors, and people with existing respiratory system ailments suffer most from ozone's effects.

Particulate matter pollution also contributes to a host of respiratory and cardiovascular ailments. Sulfur dioxide, too, is a respiratory irritant for sensitive populations.[24] In addition, it is a major component of acid rain that has damaged forests across the eastern U.S.[25]

Wind Energy Reduces Pollution and Saves Water

Wind energy is delivering substantial reductions in global warming pollution and water consumption across the U.S. Maintaining and expanding America's commitment to wind energy will produce even greater benefits.

Benefits from Existing Wind Facilities

Wind power is delivering environmental benefits across the nation by displacing generation from coal and gas plants. In 2011, the United States generated 120 million megawatt-hours (MWh) of electricity from wind power, or nearly 3 percent of electricity generated in the U.S.[26] (See Appendix A for a breakdown of wind power generation by state.)

Assuming that wind energy displaced generation from natural gas and coal-fired power plants, the environmental benefits of wind power in 2011 included:

- Avoided emissions of 68 million metric tons of carbon dioxide—as much as would have been emitted by 13 million passenger vehicles in a year (see Appendix B).
- Water savings of 26 billion gallons, more than enough to meet the annual domestic use needs of a city the size of Boston (see Appendix C).
- Reductions in air pollution, including reductions of 137,000 pounds of nitrogen oxide emissions and 91,000

pounds of sulfur dioxide emissions (see Appendix D).

Texas reaps greater savings from wind than any other state, avoiding 17 million metric tons of carbon dioxide emissions annually, or nearly 8 percent of 2009 emissions from the state's electric sector.[27] (See Figure 3 and Table 1 on p. 15.) In addition, as the state recovers from the extreme drought in 2011 that caused major rivers to run dry, wind power is averting the consumption of 6.5 billion gallons of water per year, enough to supply all the residents of Waco.

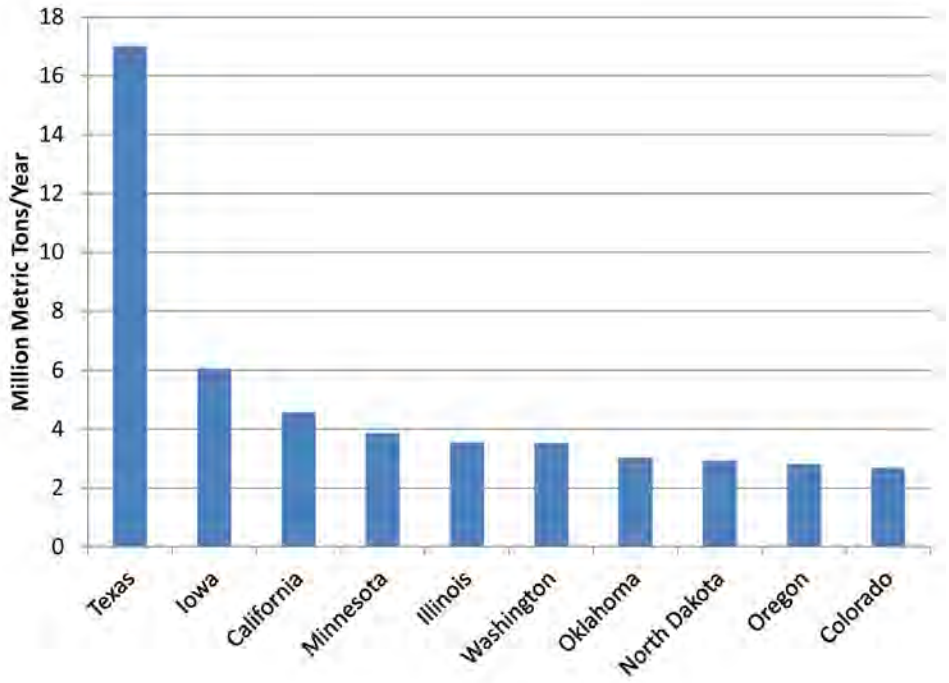
Seven of the top ten wind power-producing states are also on the list of states suffering from areas of extreme or exceptional drought in 2012.[28] Not including any new wind projects that were completed in 2012, wind power will have helped these seven states avoid consumption of 14.7 billion gallons of water at power plants, enough to serve more than 400,000 people.

The total benefits in 2012 will be greater as projects currently under construction are completed. Projects in progress could save an additional 17 million metric tons of carbon dioxide emissions per year, or as much as is emitted by 3.3 million passenger vehicles in a year. The nation can also expect to save an additional 6.5 billion gallons of water, enough for more than 175,000 people. (See appendices for full details.)

America Stands to Benefit Further if We Continue to Expand Wind Power

If construction of new wind capacity continues at a similar pace in coming years, environmental benefits will add up quickly.

Figure 3. Top 10 States for Carbon Dioxide Emission Reductions from Wind-Powered Generation in 2011



Assuming that the construction patterns observed in recent years continue, an additional 99 million MWh of electricity could be produced from wind in 2016. That would bring total generation from wind power to 249 million MWh in 2016, or 6 percent of all electricity generated in the U.S. in 2011.

Under this scenario, global warming pollution would be reduced by an additional 56 million metric tons. That is as much pollution as is released by 11 million passenger vehicles. Water savings would increase, too, with the addition of 21.6 billion gallons of savings, or enough for more than 600,000 people. This additional amount of water saved from wind energy would be almost enough to serve a city the size of Denver. Air pollution would decline by an additional 108,000 tons of nitrogen oxides and 79,000 tons of sulfur dioxide.

The U.S. has vast untapped potential wind energy. The U.S. Department of Energy estimates that 20 percent of the nation's electricity could be supplied by wind power in 2030, up from 3 percent in 2011.[29] That level of wind power could reduce electric sector water consumption by 17 percent in 2030 and cut global warming emissions by 825 million metric tons.

Table 1. Benefits of Wind Energy in Top 10 States, 2011

State	Wind Energy Production (MWh/year)	Avoided Carbon Dioxide Emissions (metric tons/year)	Water Saved (billion gallons/year)
Texas	30,051,000	17,005,000	6.54
Iowa	10,700,000	6,055,000	2.33
California	8,084,000	4,575,000	1.76
Minnesota	6,826,000	3,863,000	1.49
Illinois	6,263,000	3,544,000	1.36
Washington	6,209,000	3,514,000	1.35
Oklahoma	5,369,000	3,038,000	1.17
North Dakota	5,150,000	2,914,000	1.12
Oregon	4,961,000	2,807,000	1.08
Colorado	4,729,000	2,676,000	1.03

Table 2. Benefits in 2016 from Wind Energy Built in Top 10 States, 2013-2016, if Current Trends Continue

State	Possible New Wind Energy (MWh/year)	Avoided Carbon Dioxide Emissions (metric tons/year)	Water Saved (billion gallons/year)
Texas	20,645,000	11,683,000	4.49
Iowa	9,436,000	5,340,000	2.05
California	8,332,000	4,715,000	1.81
Oklahoma	5,761,000	3,260,000	1.25
Minnesota	5,487,000	3,105,000	1.19
Illinois	5,466,000	3,093,000	1.19
Oregon	5,012,000	2,836,000	1.09
Kansas	4,989,000	2,823,000	1.09
Washington	4,623,000	2,616,000	1.01
Colorado	4,116,000	2,329,000	0.90

America Should Continue to Invest in Wind Energy

America's clean energy boom is no accident—it is the direct result of strong, forward-thinking policies adopted over the last decade at both the state and federal levels.

As wind energy and other forms of clean, renewable energy take root in the United States—delivering ample benefits for our environment and economy—now is not the time to turn our back on further progress. To further reduce global warming pollution, curb smog and soot, move away from fossil fuels, save water, and grow our economy, the United States should continue and expand its commitment to renewable energy.

Federal Tax Incentives

Two of the most important tools that have helped grow the wind industry in the United States are the federal renewable electricity production tax credit (PTC) and the offshore wind investment tax credit (ITC).

The PTC provides a 2.2 cents per kilowatt-hour (kWh) income tax credit for utility-scale wind energy producers, helping them compete effectively with other sources of electricity by guaranteeing low electricity prices for consumers. It is available for electricity generated during the first 10 years of the

wind farm's operation. The PTC is set to expire on December 31, 2012.[30]

The offshore wind investment tax credit (ITC) is designed to address the longer timelines for development and construction of offshore wind energy facilities. It covers up to 30 percent of the cost of new wind investments and grants offshore wind developers eligibility for the credit at the point that construction begins. This is important for offshore wind because of the longer timelines for development. The offshore wind ITC also expires on December 31, 2012.[31]

Policies such as the PTC and ITC recognize that renewable energy is a key component of an electricity grid that is not only cleaner but that also delivers stable, reasonable prices for consumers. Renewable energy sources such as wind are not subject to the volatility of coal and natural gas prices, and can deliver reliable, affordable electricity for decades, making them a smart long-term investment in the nation's energy future.

Over the past 13 years, the PTC has been only sporadically available. When the PTC has been renewed by Congress for only for one or two years at a time or even allowed to expire, the environment of economic uncertainty has discouraged wind developers from building new capacity, stunting industry growth. For instance, in 2000, 2002 and 2004—years when the PTC was allowed to expire temporarily—new wind installations dropped by 93 percent, 73 percent and 77 percent, respectively, from the previous year when the PTC had been in force.[32]

The loss of the PTC could cause new construction to fall by 75 percent.[33] Failing to extend the PTC beyond 2012 could result in the loss of $10 billion in investment and 37,000 jobs in 2013, according to an analysis by Navigant Consulting for the American Wind Energy Association.[34] Opponents of tax credits like the PTC and ITC argue that they are too expensive, costing taxpayers billions of dollars per year.[35]

Strong Renewable Electricity Standards

A renewable electricity standard (RES) helps support wind energy development by requiring utilities to obtain a percentage of the electricity they provide to consumers from renewable sources. These standards help ensure that wind energy producers have a market for the electricity they generate, as electricity suppliers seek to reach their required threshold for renewable electricity. This certainty makes it easier for wind developers to finance and build new wind power installations. Today, 29 states have renewable electricity standards.[36] Some of the states with the strongest standards, such as Colorado, have seen the greatest growth in wind power generation. Raising the goals of existing state-level renewable electricity standards and adopting a national renewable electricity standard would further promote construction of wind capacity.

Transmission Infrastructure

Policymakers should prioritize upgrading and expanding existing electricity transmission infrastructure to connect areas with high electricity demand to areas of high wind energy output. Old and inefficient transmission infrastructure is one of the largest impediments to integrating more wind energy into the grid. Transmission upgrades should occur only where clearly necessary and where environmental impacts will be minimal.

Offshore Wind Resources

Some of the best wind energy resources are offshore. To capture that potential, policymakers need to set a bold goal

for offshore wind development in the Atlantic. A goal will help articulate the important role of offshore wind in America's energy future. The Department of the Interior and the Bureau of Ocean Energy Management will need sufficient staff and resources to manage multiple renewable energy leases along the coast and to promote an efficient leasing process. A coordinated effort by federal, state and regional economic development, energy and commerce agencies is needed to develop commitments to purchase offshore wind power. Finally, offshore wind projects must be sited, constructed and operated responsibly in order to avoid and mitigate conflict with local marine life and other uses.

Methodology

We obtained data on annual wind generation (in MWh) in 2011 from Energy Information Administration, *Electric Power Monthly*, February 2012.

To estimate output from wind facilities currently under construction, we obtained data on wind capacity (in MW) under construction from American Wind Energy Association (AWEA), *Wind Energy Facts* (factsheets), August 2012. We assume that the capacity factor of wind farms varies by region, shown in Table A-1, per Ryan Wiser and Mark Bolinger, *2011 Wind Technologies Market Report*, U.S. Department of Energy, August 2012. Because the state-level data did not include Alaska or Hawaii, we assumed wind projects in those states achieved the national average capacity factor of 33 percent. We assumed that the southeastern states, which have wind resources similar to the eastern region, have the same capacity factor as the East.

Our estimate of future wind energy construction is based on a national projection of an additional 34 GW of capacity from 2013 through 2016 in Navigant Consulting, for the American Wind Energy Association, *Impact of the Production Tax Credit on the U.S. Wind Market*, 12 December 2011.

Table A-1. Average Capacity Factor, Based on Projects Built from 2004-2010[37]

Region	Average Capacity Factor
East	25%
New England	28%
California	30%
Great Lakes	31%
Northwest	32%
Texas	34%
Mountain	36%
Heartland	37%

We apportioned this out to the states according to their share of the nation's existing and under-construction wind power capacity in MW, per AWEA, *Wind Energy Facts* (factsheets), August 2012. (Note that this produces results that appear to be at odds with the sum of output from existing and under-construction facilities. Some states have installed capacity (MW) that produced relatively little output (MWh) in 2011, but which was factored into future capacity and output.) We translated this future wind capacity into megawatt-hours (MWh) of generation following the same method as for facilities currently under construction, described above.

Estimating Carbon Dioxide Emission Reductions

When a wind turbine generates electricity, it displaces some other source of electricity on the grid. In the short run, this means that production at another power plant is reduced; in the longer run, it means that fewer fossil fuel-fired plants are built. In our calculations, we assume that 75 percent of the time, the power generator that is no longer producing electricity is a natural gas-powered plant and 25 percent of the time the facility is coal fired. Typically, in practice, the plant that is turned off is that with the highest marginal cost of production.

The fuel used in the marginal plant varies from region to region and from time to time based on a particular region's generating mix and prices. In the PJM generating region, which stretches from Maryland to New Jersey to Illinois, wind historically has displaced coal 60 percent of the time and natural gas and oil the rest of the time.[38] In contrast, in California and the Pacific Northwest, where a much smaller portion of electricity is generated by coal, natural gas is far more often the marginal fuel.

A ratio of 75 percent natural gas and 25 percent coal displacement is broadly representative of how wind influences the electricity grid. We obtained a national average emissions rate for coal and natural gas plants from Environmental Protection Agency, *eGRID2012 Version 1.0 Year 2009 GHG Annual Output Emission Rates*, 10 May 2012.

To put carbon dioxide emission reductions in perspective, we calculated how many passenger vehicles would have to be removed from the road in order to produce comparable savings. Data on vehicle emissions rates is from Environmental Protection Agency, *Greenhouse Gas Equivalencies Calculator*, May 2011.

Estimating Water Consumption Avoided

We estimated water savings using freshwater and saltwater consumption rates in coal, natural gas combined cycle and natural gas combustion turbine plants from U.S. Department of Energy, Office of Energy Efficiency and Renewable

Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, July 2008. We used the same assumption as for carbon dioxide savings that 75 percent of displaced generation is from natural gas and 25 percent is from coal.

We calculated how many individuals' domestic water needs could be met with this amount of saved water. We obtained state-level per capita domestic water use from Joan Kenny, et al., *Estimated Use of Water in the United States in 2005*, U.S. Geological Survey, 2009.

Estimating Avoided Emissions of Nitrogen Oxides and Sulfur Dioxide

We also estimated avoided emissions of nitrogen oxides and sulfur dioxide for each state. We calculated an average emissions rate for natural gas and coal generation in each state using 2010 nitrogen oxides and sulfur dioxide emission data from Energy Information Administration, *State Historical Tables for 2010* (EIA-767 and EIA-906), December 2011. We divided emissions by generation from natural gas and coal plants in 2010, per Energy Information Administration, *Net Generation by State by Type of Producer by Energy Source, Annual Back to 1990* (EIA-906, EIA-920 and EIA-923). We then created an average emission rate for each state based on a 25 percent coal/75 percent natural gas split.

Appendix A. Current and Future Annual Wind Generation by State

State	Rank: Existing Wind Energy	Existing Wind Energy (MWh/year)	Wind Energy Under Construction (MWh/year)	In 2016, Possible New Wind Energy (MWh/year)
Texas	1	30,051,000	4,685,000	20,645,000
Iowa	2	10,700,000	1,974,000	9,436,000
California	3	8,084,000	3,062,000	8,332,000
Minnesota	4	6,826,000	865,000	5,487,000
Illinois	5	6,263,000	1,342,000	5,466,000
Washington	6	6,209,000	586,000	4,623,000
Oklahoma	7	5,369,000	3,121,000	5,761,000
North Dakota	8	5,150,000	681,000	3,087,000
Oregon	9	4,961,000	932,000	5,012,000
Colorado	10	4,729,000	1,564,000	4,116,000
Wyoming	11	4,709,000	0	2,526,000
Kansas	12	3,759,000	4,243,000	4,989,000
Indiana	13	3,289,000	546,000	2,377,000
New York	14	2,826,000	473,000	2,030,000
South Dakota	15	2,692,000	0	1,441,000
New Mexico	16	2,089,000	85,000	1,390,000
Pennsylvania	17	1,968,000	940,000	1,663,000
Idaho	18	1,308,000	883,000	1,483,000
Montana	19	1,243,000	642,000	992,000
Wisconsin	20	1,196,000	0	972,000
Missouri	21	1,179,000	0	844,000
West Virginia	22	1,099,000	0	724,000
Nebraska	23	1,018,000	389,000	840,000
Maine	24	713,000	75,000	536,000
Utah	25	576,000	0	581,000
Michigan	26	437,000	1,358,000	1,520,000
Hawaii	27	326,000	330,000	339,000
Maryland	28	319,000	0	149,000
Arizona	29	249,000	0	426,000
Ohio	30	175,000	5,000	648,000
New Hampshire	31	78,000	105,000	215,000
Tennessee	32	53,000	0	36,000
Vermont	33	33,000	138,000	135,000
Massachusetts	34	28,000	74,000	122,000
Alaska	35	16,000	121,000	89,000
New Jersey	36	16,000	3,000	13,000
Delaware	37 (tie)	0	0	2,000
Nevada	37 (tie)	0	483,000	274,000
Rhode Island	37 (tie)	0	10,000	9,000
Virginia	37 (tie)	0	83,000	47,000

Appendix B. Annual Carbon Dioxide Emissions Avoided by Wind Energy

State	Avoided Carbon Dioxide Emissions (metric tons/year)			Vehicles Equivalent of Avoided Pollution		
	Existing Wind Energy	Wind Energy Under Construction	In 2016, Possible New Wind Energy	Existing Wind Energy	Wind Energy Under Construction	In 2016, Possible New Wind Energy
Alaska	9,000	69,000	50,000	2,000	13,000	10,000
Arizona	141,000	0	241,000	28,000	0	47,000
California	4,575,000	1,733,000	4,715,000	897,000	340,000	925,000
Colorado	2,676,000	885,000	2,329,000	525,000	174,000	457,000
Delaware	0	0	1,000	0	0	0
Hawaii	184,000	186,000	192,000	36,000	37,000	38,000
Idaho	740,000	500,000	839,000	145,000	98,000	165,000
Illinois	3,544,000	759,000	3,093,000	695,000	149,000	607,000
Indiana	1,861,000	309,000	1,345,000	365,000	61,000	264,000
Iowa	6,055,000	1,117,000	5,340,000	1,187,000	219,000	1,047,000
Kansas	2,127,000	2,401,000	2,823,000	417,000	471,000	554,000
Maine	403,000	42,000	303,000	79,000	8,000	59,000
Maryland	181,000	0	84,000	35,000	0	17,000
Massachusetts	16,000	42,000	69,000	3,000	8,000	14,000
Michigan	247,000	768,000	860,000	48,000	151,000	169,000
Minnesota	3,863,000	490,000	3,105,000	757,000	96,000	609,000
Missouri	667,000	0	477,000	131,000	0	94,000
Montana	703,000	363,000	561,000	138,000	71,000	110,000
Nebraska	576,000	220,000	475,000	113,000	43,000	93,000
Nevada	0	273,000	155,000	0	54,000	30,000
New Hampshire	44,000	59,000	122,000	9,000	12,000	24,000
New Jersey	9,000	2,000	7,000	2,000	0	1,000
New Mexico	1,182,000	48,000	786,000	232,000	9,000	154,000
New York	1,599,000	268,000	1,149,000	314,000	52,000	225,000
North Dakota	2,914,000	385,000	1,747,000	571,000	76,000	342,000
Ohio	99,000	3,000	367,000	19,000	1,000	72,000
Oklahoma	3,038,000	1,766,000	3,260,000	596,000	346,000	639,000
Oregon	2,807,000	527,000	2,836,000	550,000	103,000	556,000
Pennsylvania	1,114,000	532,000	941,000	218,000	104,000	185,000
Rhode Island	0	6,000	5,000	0	1,000	1,000
South Dakota	1,523,000	0	816,000	299,000	0	160,000
Tennessee	30,000	0	20,000	6,000	0	4,000
Texas	17,005,000	2,651,000	11,683,000	3,334,000	520,000	2,291,000
Utah	326,000	0	329,000	64,000	0	65,000
Vermont	19,000	78,000	77,000	4,000	15,000	15,000
Virginia	0	47,000	27,000	0	9,000	5,000
Washington	3,514,000	332,000	2,616,000	689,000	65,000	513,000
West Virginia	622,000	0	410,000	122,000	0	80,000
Wisconsin	677,000	0	550,000	133,000	0	108,000
Wyoming	2,665,000	0	1,429,000	523,000	0	280,000

Appendix C. Annual Water Consumption Avoided with Wind Energy

	Water Saved (million gallons/year)			Water Saved Could Provide Domestic Water for This Many People		
State	Existing Wind Energy	Wind Energy Under Construction	In 2016, Possible New Wind Energy	Existing Wind Energy	Wind Energy Under Construction	In 2016, Possible New Wind Energy
Alaska	3	26	19	100	800	600
Arizona	54	0	93	1,100	0	1,800
California	1,759	666	1,813	38,900	14,700	40,100
Colorado	1,029	340	896	23,300	7,700	20,300
Delaware	0	0	1	0	0	0
Hawaii	71	72	74	1,200	1,200	1,200
Idaho	285	192	323	4,200	2,800	4,700
Illinois	1,363	292	1,189	41,500	8,900	36,200
Indiana	716	119	517	25,800	4,300	18,600
Iowa	2,328	430	2,053	98,100	18,100	86,500
Kansas	818	923	1,086	27,700	31,200	36,700
Maine	155	16	117	7,900	800	5,900
Maryland	69	0	32	1,700	0	800
Massachusetts	6	16	26	200	500	900
Michigan	95	295	331	3,300	10,100	11,300
Minnesota	1,485	188	1,194	59,800	7,600	48,100
Missouri	257	0	184	8,000	0	5,700
Montana	270	140	216	6,600	3,400	5,300
Nebraska	222	85	183	4,500	1,700	3,700
Nevada	0	105	60	0	1,500	900
New Hampshire	17	23	47	600	800	1,700
New Jersey	3	1	3	100	0	100
New Mexico	455	19	302	11,600	500	7,700
New York	615	103	442	17,400	2,900	12,500
North Dakota	1,121	148	672	33,700	4,500	20,200
Ohio	38	1	141	1,500	0	5,600
Oklahoma	1,168	679	1,254	37,700	21,900	40,400
Oregon	1,080	203	1,091	24,400	4,600	24,700
Pennsylvania	428	204	362	20,600	9,800	17,400
Rhode Island	0	2	2	0	100	100
South Dakota	586	0	314	17,100	0	9,100
Tennessee	12	0	8	400	0	300
Texas	6,539	1,019	4,492	130,800	20,400	89,800
Utah	125	0	126	1,800	0	1,900
Vermont	7	30	29	300	1,300	1,300
Virginia	0	18	10	0	700	400
Washington	1,351	127	1,006	35,900	3,400	26,800
West Virginia	239	0	158	6,500	0	4,300
Wisconsin	260	0	211	12,500	0	10,200
Wyoming	1,025	0	550	18,500	0	9,900

Appendix D. Annual Nitrogen Oxide and Sulfur Dioxide Emissions Avoided with Wind Energy

	Avoided NO_x Emissions (tons/year)			Avoided SO_2 Emissions (tons/year)		
State	Existing Wind Energy	Wind Energy Under Construction	In 2016, Possible New Wind Energy	Existing Wind Energy	Wind Energy Under Construction	In 2016, Possible New Wind Energy
Alaska	40	310	230	20	120	90
Arizona	100	0	180	50	0	90
California	6,110	2,310	6,300	1,730	650	1,780
Colorado	3,680	1,220	3,210	1,700	560	1,480
Delaware	0	0	0	0	0	0
Hawaii	70	70	80	70	70	80
Idaho	9,310	6,280	10,550	14,050	9,490	15,940
Illinois	3,310	710	2,890	4,270	910	3,720
Indiana	1,710	280	1,230	3,100	520	2,240
Iowa	8,480	1,560	7,480	7,420	1,370	6,540
Kansas	5,540	6,250	7,350	1,290	1,460	1,720
Maine	670	70	500	1,110	120	840
Maryland	310	0	140	160	0	70
Massachusetts	10	20	40	30	80	140
Michigan	260	820	920	420	1,310	1,470
Minnesota	5,480	690	4,400	3,480	440	2,800
Missouri	520	0	370	1,000	0	720
Montana	5,450	2,810	4,350	340	180	270
Nebraska	1,290	490	1,060	780	300	640
Nevada	0	270	160	0	140	80
New Hampshire	30	40	80	230	310	630
New Jersey	10	0	10	10	0	10
New Mexico	1,830	70	1,220	340	10	230
New York	1,420	240	1,020	2,940	490	2,110
North Carolina	0	0	0	0	0	0
North Dakota	35,050	4,630	21,010	5,750	760	3,450
Ohio	70	0	250	240	10	880
Oklahoma	4,940	2,870	5,300	3,810	2,220	4,090
Oregon	3,470	650	3,510	4,700	880	4,750
Pennsylvania	780	370	660	1,880	900	1,590
Rhode Island	0	0	0	0	0	0
South Dakota	3,530	0	1,890	2,670	0	1,430
Tennessee	30	0	20	40	0	30
Texas	16,780	2,620	11,530	22,990	3,580	15,800
Utah	390	0	390	120	0	120
Vermont	10	60	60	0	0	0
Virginia	0	50	30	0	100	50
Washington	3,850	360	2,870	600	60	450
West Virginia	640	0	420	410	0	270
Wisconsin	600	0	480	1,030	0	840
Wyoming	10,740	0	5,760	2,040	0	1,090

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Wind Energy For A Cleaner America II

Wind Energy's Growing Benefits for Our Environment and Our Health

ENVIRONMENT AMERICA
RESEARCH & POLICY CENTER

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Wind Energy's Growing Benefits for Our Environment and Our Health

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Executive Summary

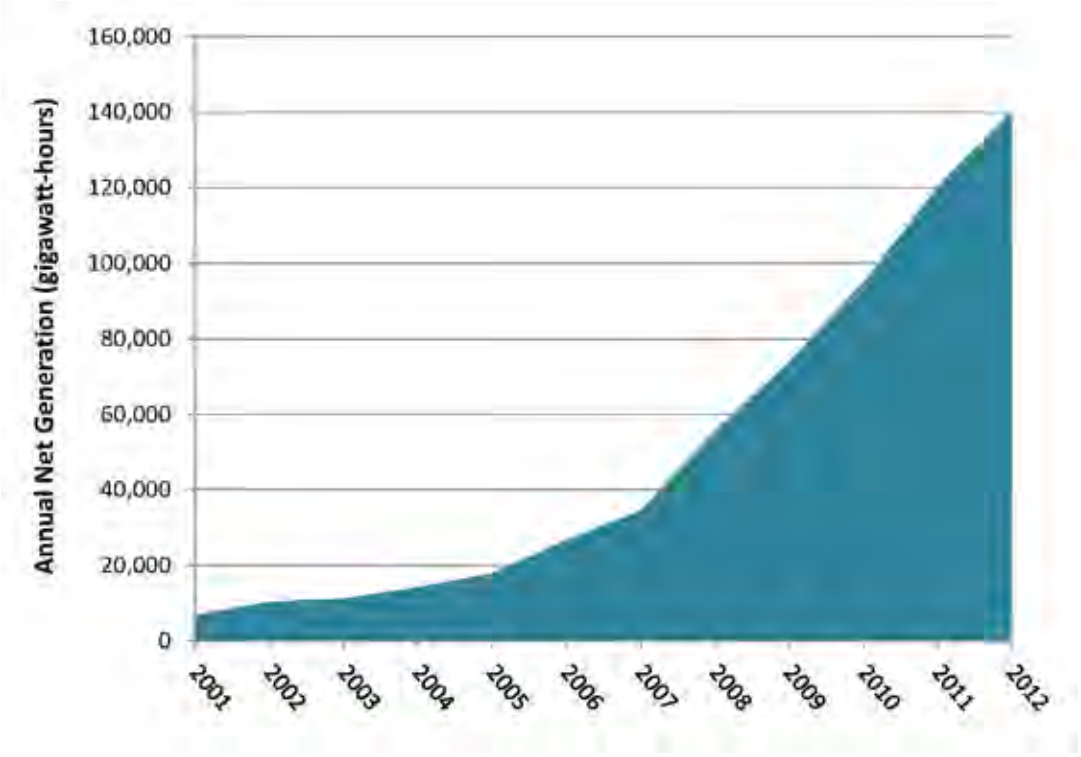
Burning fossil fuels to generate electricity pollutes our air, contributes to global warming, and consumes vast amounts of water—harming our rivers and lakes and leaving less water for other uses. In contrast, wind energy produces no air pollution, makes no contribution to global warming, and uses no water.

America's wind power capacity has quadrupled in the last five years and wind energy now generates as much electricity as is used every year in Georgia. Thanks to wind energy, America uses less water for power plants and produces less climate-altering carbon pollution.

Wind energy displaced about 84.7 million metric tons of carbon dioxide emissions in 2012—more global warming-inducing carbon dioxide pollution than is produced annually in Massachusetts, Maryland, South Carolina or Washington state. Wind energy also saves enough water nationwide to meet the domestic water needs of more than a million people.

America has vast wind energy resources, and there is still plenty of room for growth. But the pending expiration of the federal renewable energy production tax credit and investment tax credit threatens the future expansion of wind power. To protect the

Figure ES-1. Growth in Electricity Generated by Wind Power[1]



environment, federal and state governments should continue and expand policies that support wind energy.

Wind energy is on the rise in the United States.

- Electricity generated with wind power quadrupled in the last five years, from about 34,500 gigawatt-hours (GWh) in 2007 to more than 140,000 GWh at the end of 2012—or as much electricity as is used each year in Georgia. (See Figure ES-1.)
- Wind energy was the largest source of new electricity capacity added to the grid in 2012.
- Nine states now have enough wind turbines to supply 12 percent or more of their annual electricity needs in an average year, with Iowa, South Dakota and Kansas now possessing enough wind turbines to supply more than 20 percent of their annual electricity needs.

By displacing dirty electricity from fossil fuel-fired power plants, wind energy saves water and reduces pollution. In 2012, wind energy helped the United States:

- **Avoid 84.7 million metric tons of carbon dioxide pollution—or as much pollution as is produced by more than 17 million of today's passenger vehicles in a year.** Fossil fuel-fired power plants are the nation's largest source of carbon dioxide, the leading global warming pollutant. In the United States, warmer temperatures caused by global warming have already increased the frequency and severity of heat waves and heavy downpours, resulting in more intense wildfires, floods, droughts, and tropical storms and hurricanes.
- **Save enough water to supply the annual domestic water needs of more than a million people.** Power plants use water for cooling, reducing the amount of water available for irrigation, wildlife, recreation or domestic use. More water is withdrawn from U.S. lakes, rivers, streams and aquifers for the purpose of cooling power plants than for any other purpose.
- **Avoid 79,600 tons of nitrogen oxide (NO_x) and 98,400 tons of sulfur dioxide emissions.** Nitrogen oxides are a key ingredient of smog, which contributes to asthma and other respiratory problems; power plants are responsible for about 15 percent of the nation's total nitrogen oxide (NO_x) pollution each year. Power plants also produce about 60 percent of all sulfur dioxide pollution, which contributes to acid rain. Finally, coal-fired power plants emit heavy metals such as mercury, a potent neurotoxicant that can cause developmental and neurological disorders in babies and children. Nearly two-thirds of all airborne mercury pollution in the United States in 2010 came from the smokestacks of coal-fired power plants.

If America were to continue to add onshore wind capacity at the rate it did from 2007 to 2012, and take the first steps toward development of its massive potential for offshore wind, by 2018 wind energy will be delivering the following benefits:

- Averting a total of 157 million metric tons of carbon dioxide pollution annually—or more carbon dioxide pollution than was produced by Georgia, Michigan or New York in 2011.
- Saving enough water to supply the annual domestic water needs of 2.1 million people—roughly as many people as live in the city of Houston and more than live in Philadelphia, Phoenix or San Diego.
- Averting more than 121,000 tons of smog-forming nitrogen oxide pollution and 194,000 tons of sulfur dioxide pollution each year.

Wind energy's success in reducing air pollution and saving water will continue to grow if America makes a stable, long-term commitment to clean energy at the local, state and national levels. Specific policies that are essential to the development of wind energy include:

- The federal renewable energy **production tax credit** (PTC) and **investment tax credit** (ITC). The PTC provides an income tax credit of 2.3 cents per kilowatt-hour (kWh) for utility-scale wind energy producers for 10 years, while the ITC covers up to 30 percent of the capital cost of new renewable energy investments. Wind energy developers can take one of the two credits, which help reduce the financial risk of renewable energy investments and create new financing opportunities for wind energy. Both the ITC and the PTC, however, are scheduled to expire at the end of 2013.
- Strong **renewable electricity standards**. A strong renewable electricity standard (RES) helps support wind energy development by requiring utilities to obtain a percentage of the electricity they provide to consumers from renewable sources. These standards help ensure that wind energy producers have a market for the electricity they generate and protect consumers from the sharp swings in energy prices that accompany over-reliance on fossil fuels. Today, 29 states have renewable electricity standards—other states and the federal government should follow their lead.
- Continued coordination and collaboration between state and federal agencies to expedite **siting of offshore wind facilities** in areas that avoid environmental harm.

Introduction

From the Pacific Coast to the Great Plains to the Atlantic Ocean, wind power is on the rise in the United States, producing an increasing share of our electricity with minimal impact on the environment.

Just a decade ago, wind energy was a trivial part of the nation's electricity picture. Today, wind energy is one of the fastest growing forms of electricity generation and an increasingly important part of the nation's energy mix.

The remarkable progress of wind energy is generating real environmental results. Wind energy is reducing demand for electricity from fossil fuels such as coal and natural gas—curbing emissions that cause global warming while minimizing the use of water for cooling.

The boom in wind power is no accident, however. State and federal policy-makers have implemented far-sighted public policies that have created the conditions under which wind energy can thrive. By unleashing the energies of innovative companies and American workers, and tapping the natural power of the wind, these public policies are moving the nation toward a clean energy future and delivering growing benefits for our environment and our health.

With the environmental and economic advantages of wind energy becoming ever more apparent, now is the time for our leaders to renew their commitment to the key public policies that will enable the nation to achieve even greater benefits in the years to come.

Wind Energy Is Growing Rapidly in The U.S.

Wind energy is quickly becoming an important part of the energy mix in the United States. Nationwide, electricity generation from wind power has quadrupled in the last five years, from 34,500 GWh in 2007 to more than 140,000 GWh in 2012—or as much electricity as is used each year in the state of Georgia.[2] (See Figure 1.) Nine states now have enough wind turbines to produce 12 percent or more of their annual electricity needs in an average year—with Iowa, South Dakota and Kansas now having enough wind energy capacity to produce 20 percent or more of their annual electricity needs in a typical year.[3]

With more than 10,000 MW of new wind capacity installed in 2012, wind energy became the largest source of new electricity generating capacity in the United States last year—ahead of even natural gas, which added about 8,746 MW of new capacity.[5] In 2012, wind energy accounted for more than 40 percent of the new electric generating capacity added to the grid in the United States, making it the nation's largest source of new generating capacity.[6] (See Figure 2.)

Figure 1. Growth in Electricity Generated by Wind Power[4]

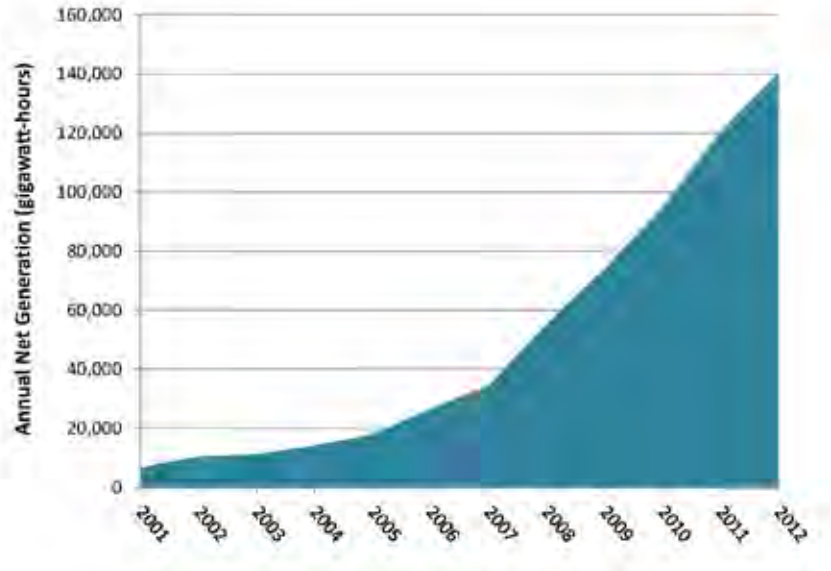
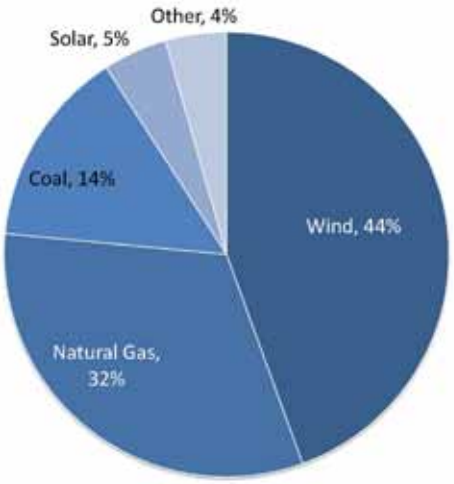


Figure 2. New Electricity Capacity Additions by Technology, 2012[7]



Employment in the wind industry has also grown significantly. In 2003, the wind industry directly employed 24,300 people.[8] By 2012, that number had more than tripled to more than 80,000 people.[9]

As the wind industry has grown and technology has advanced, the cost of wind energy has declined. By 2013, these cost declines had led wind energy to be competitive with other forms of power generation. When the costs imposed by emissions of global warming pollution are factored in, wind power is less expensive than new coal-fired power plants and is competitive with new natural gas power plants and even existing coal-fired plants.[10]

Power Plants Damage the Environment

Burning coal and natural gas to generate electricity damages the environment by contributing to global warming, consuming vast quantities of water, and creating health-threatening air pollution. Wind energy has none of these problems—it emits no air pollution and consumes little or no water. Generating clean electricity using wind power reduces the need for dirty electricity from fossil fuel-fired power plants, avoiding millions of tons of harmful air pollution and saving millions of gallons of water.

Power Plants Are America's Leading Source of Global Warming Pollution

Fossil fuel-fired power plants are the nation's largest source of carbon dioxide pollution, the leading global warming pollutant.[11] In 2011, power plants were responsible for 42 percent of all U.S. global warming pollution.[12] (See Figure 3.)

Figure 3. Energy-Related Carbon Dioxide Emissions by Sector in the U.S., 2011, with Electricity Generation Broken Down by Fuel[13]

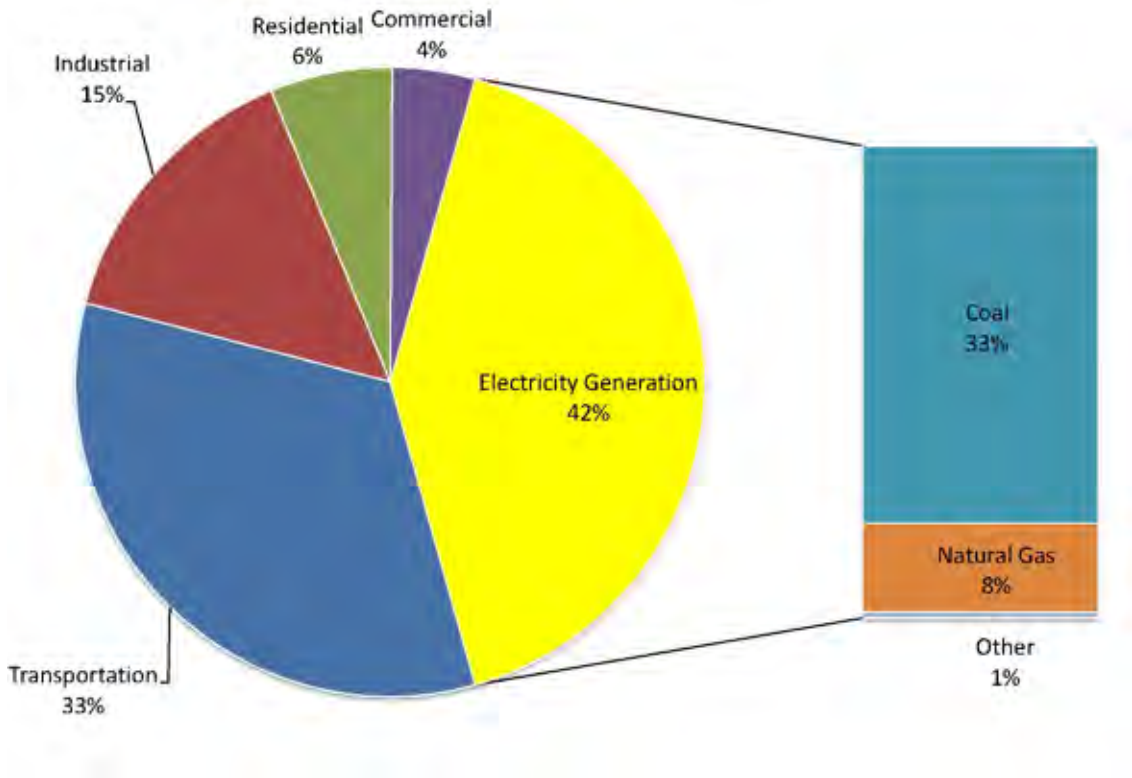
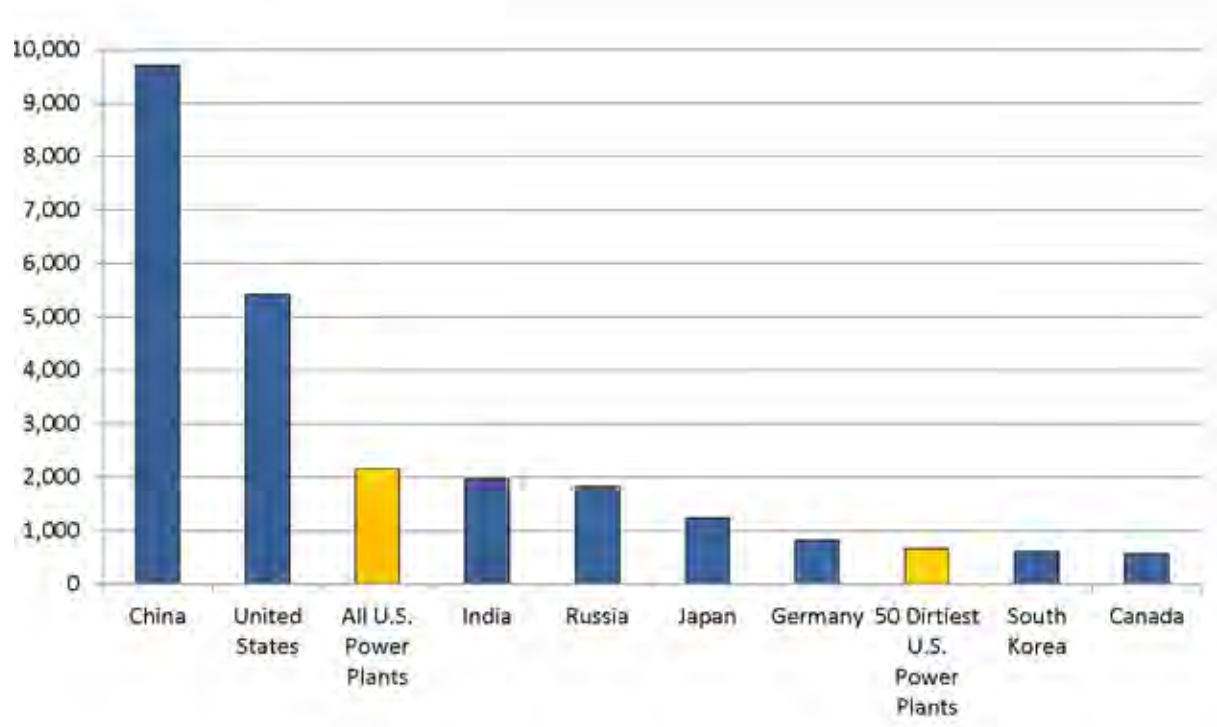


Figure 4. 50 Dirtiest U.S. Power Plants Compared to Total Emissions from Other Countries (MMT CO_2)[15]



America's power plants are also among the most significant sources of carbon dioxide pollution in the world. For example, if the U.S. power sector were an independent nation, it would be the third-largest emitter of carbon dioxide pollution in the world, behind China and the United States as a whole.[14] A large share of those emissions come from just a small number of old, dirty coal-fired power plants. The carbon dioxide pollution coming from America's 50 dirtiest power plants, for example, is greater than the amount of pollution produced annually by the entire economies of South Korea or Canada. (See Figure 4.)

The United States is already feeling the impacts of global warming. In the last 50 years the U.S. average annual temperature has risen 2° F, and experts project that it will continue rising.[16] Depending on the scale of continued greenhouse gas emissions, global average annual surface temperatures are likely to increase by 0.5°F to 8.6 °F by 2100, according to the most recent assessment by the Intergovernmental Panel on Climate Change (IPCC).[17]

Warmer average annual temperatures are connected to increases in extreme precipitation and more intense heat waves.[18] In the United States, extreme downpours now happen 30 percent more often nationwide than in 1948, and the largest annual storms now produce 10 percent more precipitation on average.[19] Meanwhile, the number of heat waves in the United States has increased since 1960 while the projected time between prolonged dry spells has become shorter.[20] The U.S. has also experienced an increase in the frequency and severity of other extreme weather events, including floods, more intense wildfires, and stronger tropical storms and hurricanes.[21]

Sea levels have risen eight inches along some parts of the U.S. coastline in the past 50 years. Rising seas erode shorelines—putting homes, businesses and infrastructure at risk—and can cause saltwater intrusion into coastal fresh water aquifers, leaving some unusable without desalination.[22] According to the IPCC, sea levels are likely to rise 10 to 32 inches by the

late 21st century; in the worst case, sea levels could rise by as much as 38 inches.[23]

Science tells us that these and other impacts are expected to become more pronounced in the decades to come, unless we cut the dangerous carbon pollution that is fueling the problem. Increasing our production of wind power will help the United States make the emissions reductions necessary to forestall the worst impacts of global warming.

Power Plants Use Lots of Water

Fossil fuel power plants use vast amounts of water for cooling.

There are two ways to measure the use of water in power plants. *Withdrawals* represent the amount of water taken from waterways or groundwater for use in a power plant, regardless of whether that water is eventually returned to the river, lake or aquifer from which it came. More water is withdrawn from U.S. lakes, rivers, streams and aquifers to cool power plants than for any other purpose.[24] Water *consumption* reflects the amount of water that is lost to a given watershed as a result of its use in power plants, with losses primarily taking place through evaporation.

Almost all fossil fuel-fired power plants use water for cooling, but different power plant technologies have differing impacts on water supplies. Once-through cooling systems withdraw vast amounts of water for cooling and return it—usually at a higher temperature—to the waterways from which it came. Recirculating systems use the same water for cooling multiple times, reducing withdrawals, but plants with recirculating systems typically *consume* more water than once-through systems due to higher losses from evaporation.[25]

Regardless of the type of cooling system used, water use in power plants can create big problems for the environment. Large-scale water withdrawals for power plants can deplete groundwater supplies and affect the ecosystems of the waterways on which they depend. Fish and other aquatic life can be sucked into power plant intakes, while the discharge of heated water can also harm wildlife. Water discharged from a power plant can be 17 degrees hotter than it was when it was withdrawn for cooling.[26] This hotter water can affect the health and viability of the plants and animals living in the receiving waterway by subjecting organisms to water temperatures higher than they are able to tolerate and by depriving the waterway of dissolved oxygen. A 2013 study estimated that half of all power plant cooling systems discharge water at temperatures that can harm aquatic life.[27]

Recirculating cooling systems withdraw less water from waterways and aquifers, but lose more of that water to evaporation, potentially exacerbating local water supply problems. Many regions of the United States currently struggle to balance demands for water from industry, agriculture, and residential and commercial users while maintaining sufficient water levels in rivers and streams to preserve healthy ecosystems. Water consumption in power plants adds to those demands. In arid regions, power plants contribute to the long-term drawdown of critical groundwater supplies. In the Southwest and California, approximately one-third to two-thirds of the water consumed by power plants comes from groundwater.[28]

Power Plants Create Harmful Air Pollution

Coal- and natural gas-fired power plants also produce pollution that contributes to ozone smog, particulate matter and acid rain. This pollution hurts public health and ecosystems.

Each year, power plants are responsible for about 15 percent of the nation's emissions of nitrogen oxides (NO_x) – a key ingredient in ozone smog.[29] When inhaled, ozone quickly reacts with airway tissues and produces inflammation similar to sunburn on the

inside of the lungs. This inflammation makes lung tissues less elastic, more sensitive to allergens, and less able to ward off infections.[30] Minor exposure to ozone can cause coughing, wheezing and throat irritation. Constant exposure to ozone over time can permanently damage lung tissues, decrease the ability to breathe normally, and exacerbate or potentially even cause chronic diseases like asthma.[31] Children, adults who are active outdoors, and people with existing respiratory system ailments suffer most from ozone's effects.

Particulate matter pollution also contributes to a host of respiratory and cardiovascular ailments. Sulfur dioxide, too, is a respiratory irritant for sensitive populations.[32] It is also a major component of acid rain that has damaged forests across the eastern United States.[33] Power plants are responsible for nearly 60 percent of U.S. sulfur dioxide pollution annually.[34]

Finally, nearly two-thirds of all airborne mercury pollution in the United States in 2010 came from the smokestacks of coal-fired power plants.[35] Mercury is a potent neurotoxicant, and exposure to mercury during critical periods of brain development can contribute to irreversible deficits in verbal skills, damage to attention and motor control and reduced IQ.[36]

Wind Energy Reduces Pollution and Saves Water

In 2012, the United States generated 140,000 gigawatt-hours (GWh) of electricity from wind power—or as much as electricity as was used in the state of Georgia in 2011.[37] (See Appendix A for a breakdown of wind power generation and its benefits by state.)

Assuming that wind energy displaced generation from natural gas and coal-fired power plants, the environmental benefits of wind power in 2012 included:

- Avoided emissions of 84.7 million metric tons of carbon dioxide, the leading global warming pollutant—as much as would have been emitted by 17.6 million passenger vehicles in a year (see Appendix B).[38] That's more than all the energy-related carbon dioxide emissions in Massachusetts, Maryland, South Carolina or Washington state in 2011.[39]
- Water savings of nearly 38 billion gallons, more than enough to meet the annual domestic water needs of more than a million people (see Appendix C).[40]
- Reductions in air pollution, including reductions of 79,600 tons of nitrogen oxide emissions and 98,400 tons of sulfur dioxide emissions (see Appendix D).[41]

Texas reaps greater savings from wind energy than any other state, avoiding 19.3 million metric tons of carbon dioxide emissions annually, or about 8 percent of 2011 emissions from the state's electric sector.[42] (See Figure 5 and Table 1, next page.) In addition, as the state recovers from the extreme drought in 2011 that caused major rivers run dry, wind power is averting the consumption of at least 8.6 billion gallons of water per year, enough to supply the domestic water needs of more than 172,000 people.

Figure 5. Top 10 States for Carbon Dioxide Emission Reductions from Wind Power in 2012

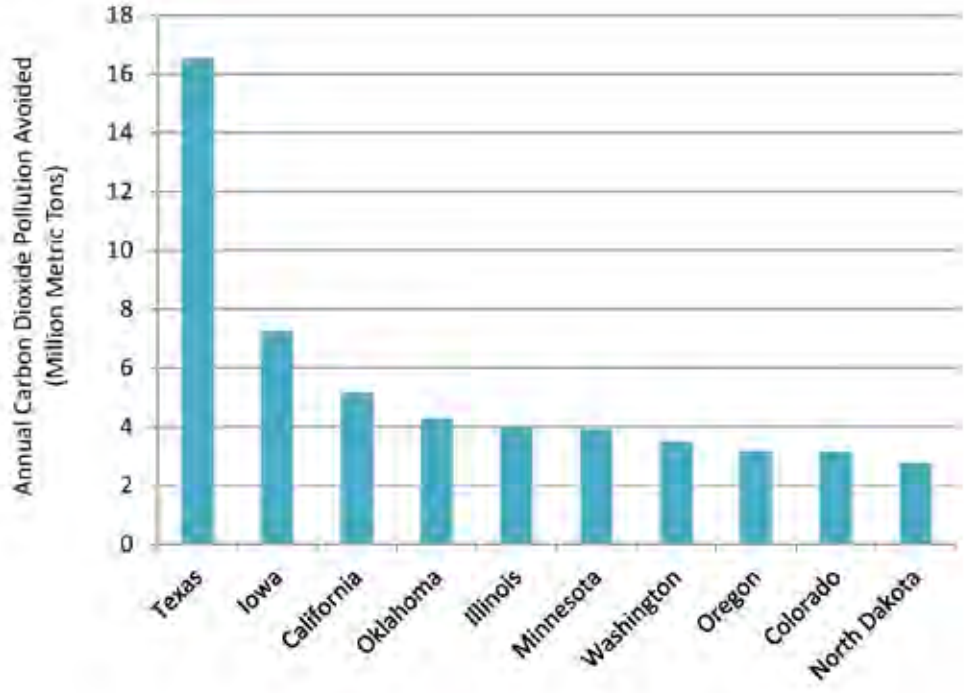


Table 1. Benefits of Wind Energy in Top 10 States, 2012

State	Wind Power Generation (GWh)	Avoided Carbon Dioxide Emissions (million metric tons)	Water Saved (million gallons)
Texas	31,860,000	19.3	8,610
Iowa	13,945,000	8.4	3,769
California	9,937,000	6.0	2,685
Oklahoma	8,234,000	5.0	2,225
Illinois	7,708,000	4.7	2,083
Minnesota	7,529,000	4.6	2,035
Washington	6,688,000	4.0	1,807
Oregon	6,066,000	3.7	1,639
Colorado	6,045,000	3.7	1,634
North Dakota	5,316,000	3.2	1,437

Seven of the top ten wind power-producing states are also on the list of states that suffered from areas of extreme or exceptional drought in 2012.[43] Collectively, wind power helped these seven states avoid consumption of 27.9 billion gallons of water at power plants, enough to serve the annual domestic water needs of 773,000 people—or nearly all the residents of Fort Worth.[44]

America Stands to Benefit Further if We Continue to Expand Wind Power

From the wide plains of the Midwest to the river valleys of the Pacific Northwest to the shores of the Atlantic Ocean, the United States has only scratched the surface of its vast wind energy potential. Tapping just a fraction of this potential by maintaining and expanding America's commitment to wind energy will produce even greater benefits.

Wind turbines can be placed virtually anywhere the wind blows. A 2012 report by the National Renewable Energy Laboratory estimates that as a whole, the United States has the technical potential to install nearly 11,000 GW of onshore wind capacity, and another 4,200 GW of offshore wind capacity.[45] (See Figures 6 and 7.) That amount of wind capacity could produce nearly 49.8 million GWh of electricity annually—12 times the amount of electricity generated in the United States in 2012.[46]

If the United States were to install wind energy between now and 2018 at the same pace that it did from 2007 to 2012, in five years, wind energy would help the United States:

- Avoid 157 million metric tons of carbon dioxide pollution annually—or as much as that emitted by 32 million of today's passenger vehicles in a year.[49] That's also more than all the energy-related emissions of Georgia, Michigan or New York in 2011.[50]
- Save enough water to supply the annual domestic water needs of 2.1 million people—roughly as many people as live in the city of Houston and more than live in Philadelphia, Phoenix or San Diego.
- Averting more than 121,000 tons of smog-forming nitrogen oxide pollution and 194,000 tons of sulfur dioxide pollution each year.

Figure 6: Onshore Wind Energy Technical Potential by State, 2012[47]

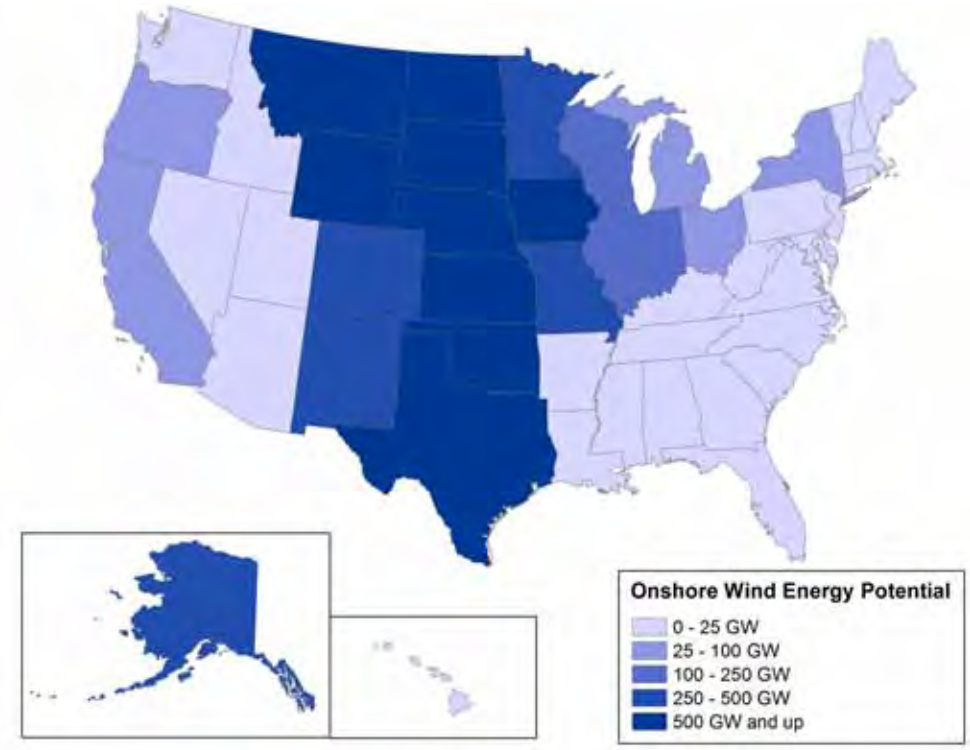
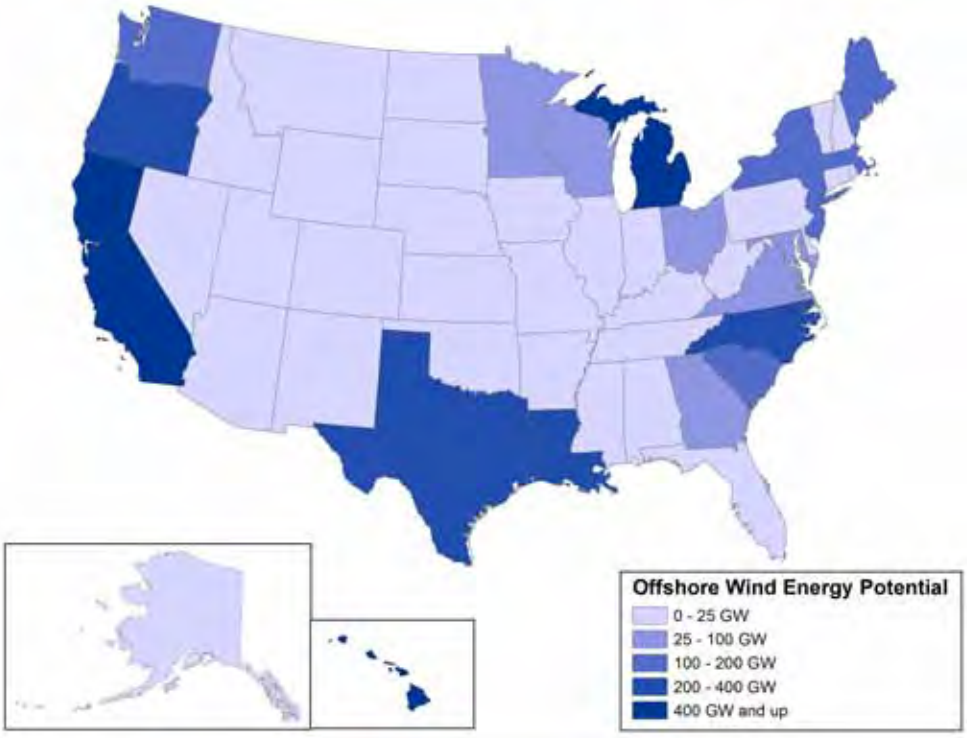


Figure 7: Offshore Wind Energy Technical Potential by State, 2012[48]



America Should Continue to Invest in Wind Energy

America's clean energy boom is no accident. It is the direct result of strong, forward-thinking policies adopted over the last decade at both the state and federal levels, policies that have unleashed the energy of innovative companies and American workers to fuel dramatic growth in renewable energy. As wind energy and other forms of clean, renewable energy take root in the United States—delivering ample benefits for our environment and economy—now is not the time to turn our back on further progress. To further reduce global warming pollution, curb smog and soot, move away from fossil fuels, save water, and grow our economy, the United States should make a long-term commitment to renewable energy with policies to support growth of the wind industry.

Federal Tax Incentives

Two of the most important tools that have helped grow the wind industry in the United States are the federal renewable electricity production tax credit (PTC) and the investment tax credit (ITC).

Policies such as the PTC and ITC recognize that renewable energy is a key component of an electricity grid that is not only cleaner but that also delivers stable, reasonable prices for consumers. Renewable energy sources such as wind are not subject to the fuel price volatility of coal and natural gas, and can deliver reliable, affordable electricity for decades, making them a smart long-term investment in the nation's energy future. However, renewable energy projects are often capital intensive. Unlike fossil fuel power plants, for which fuel costs represent a significant share of the overall cost of producing power, the vast majority of the costs of building a wind turbine or installing a solar panel are incurred before the first kilowatt-hour of electricity is produced. Public policies that defray some of those initial capital costs, or that help assure a reliable rate of return over the long term, can reduce the risk for investors—opening the floodgates for investment and the rapid expansion of renewable energy.

The PTC provides an income tax credit of 2.3 cents per kilowatt-hour (kWh) for utility-scale wind energy producers.[51] It is available for electricity generated during the first 10 years of the wind farm's operation. After expiring at the end of 2012, the PTC was renewed in January 2013 and will be available for all projects that begin construction on or before December 31, 2013.

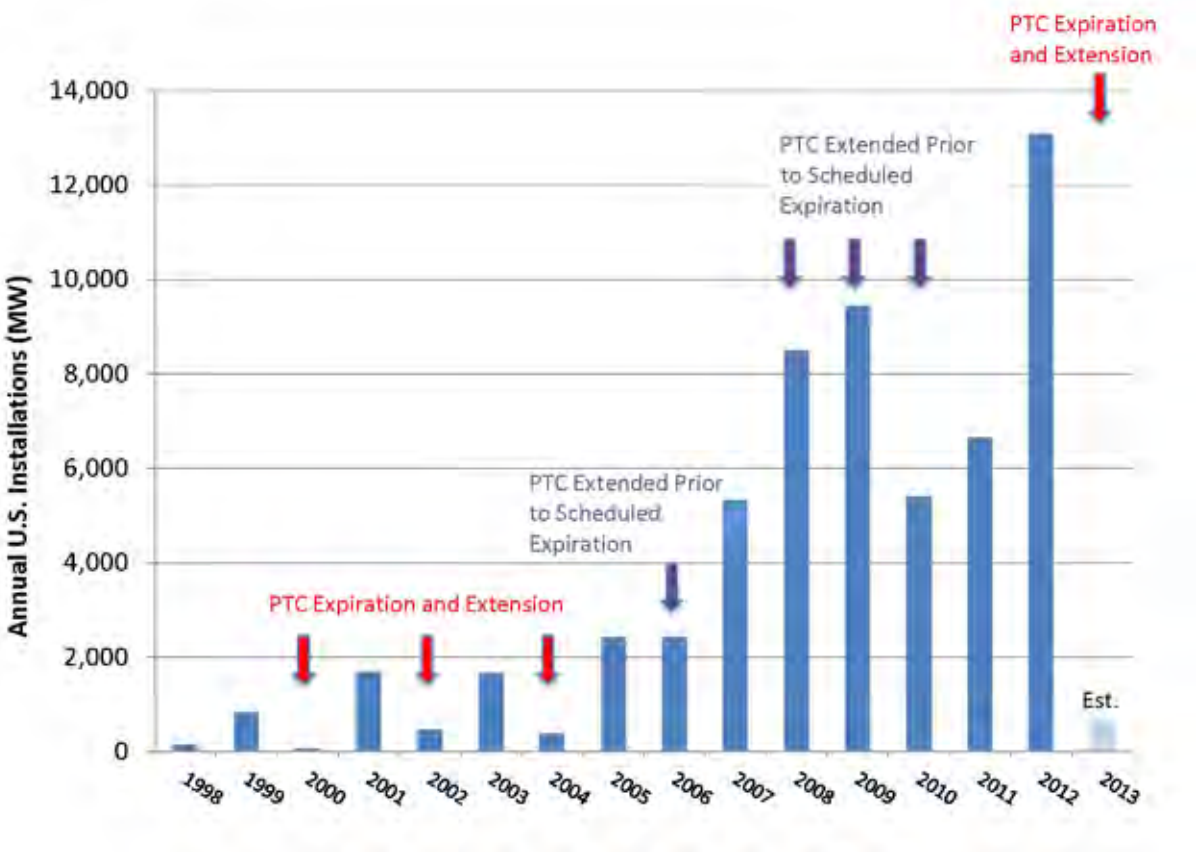
The investment tax credit (ITC) covers up to 30 percent of the capital cost of new renewable energy investments, with the credit becoming available the moment the wind energy system is placed into service. The ITC also expires on December 31, 2013.[52]

Wind energy developers and other builders of renewable energy systems may choose to take advantage of either the PTC or the ITC, but not both. Different types of renewable energy projects stand to reap greater benefits from one or the other program, depending in part on the capital intensity of the

project and the amount of power it produces over time.[53] Federal renewable energy tax credits have been a key contributor to the growth of wind energy over the last decade, but their effectiveness has been hamstrung by their "here today, gone tomorrow" inconsistency. Over the past 13 years, the renewable energy PTC has been available only sporadically. When the PTC has been renewed by Congress for only for one or two years at a time or even allowed to expire, the ensuing uncertainty has discouraged wind developers from building new capacity, stunting industry growth. For instance, in 2000, 2002 and 2004—years when the PTC was allowed to expire temporarily—new wind installations dropped by 93 percent, 73 percent and 77 percent, respectively, from the previous year when the PTC had been in force.[54] (See Figure 8.)

The economic uncertainty created by the sporadic availability of incentives discourages businesses that manufacture turbines, gear boxes, blades, bearings and towers from entering the market or expanding, restricting the supply chain and increasing costs. On the other hand, long-term consistency in renewable energy policy can encourage new businesses to enter the field and expand operations, bringing new jobs and investment to the United States. For example, between 2005-2006 and 2012—a period of relative stability in clean energy incentives—the amount of domestically produced content in U.S. wind power projects increased from 25 percent to 72 percent, creating new jobs and economic opportunity in the United States.[55]

Figure 8. The Impact of the Sporadic Expiration and Renewal of the PTC on the Wind Industry[56]



Establish Strong Renewable Electricity Standards

A renewable electricity standard (RES) helps support wind energy development by requiring utilities to obtain a percentage of the electricity they provide to consumers from renewable sources. These standards help ensure that wind energy producers have a market for the electricity they generate, as electricity suppliers seek to reach their required threshold for renewable electricity. This certainty makes it easier for wind developers to finance and build new wind power installations. Today, 29 states have renewable electricity standards.[57] From 1999 through 2012, 69 percent of all new wind capacity was built in states with renewable electricity standards.[58] In 2012, the proportion rose to 83 percent.[59] Some of the states with the strongest standards, such as Colorado, have seen the greatest growth in wind power generation.[60]

Renewable electricity standards have not only proven to be effective at spurring wind energy development, but they have also had little effect on ratepayers, with most policies resulting in either a small net benefit or a small cost to ratepayers on the order of $5 per year.[61] This does not include the economic value of the environmental and public health benefits of renewable energy, nor does it reflect the economic benefits of wind energy-driven job creation, leading to the conclusion that renewable electricity standards are a winner for both the environment and the economy.

In order for RES policies to continue to drive wind energy growth, however, states without RESs will need to adopt them, those with policies will need to strengthen them, and the federal government will need to adopt a national policy of its own. According to the U.S. Department of Energy, existing state RESs will drive the addition of only 3 to 5 GW of renewable energy per year between now and the end of the decade, which is lower than the amount of wind energy added in recent years.[62] Strengthening the nation's renewable energy goals will help keep the United States on pace to tap an increasing share of its wind energy potential.

Facilitate Development of Offshore Wind Resources

Some of the best wind energy resources are offshore. To capture that potential, policymakers need to set a bold goal for offshore wind development in the Atlantic. A goal will help articulate the important role of offshore wind in America's energy future. The Department of the Interior and the Bureau of Ocean Energy Management will need sufficient staff and resources to manage multiple renewable energy leases along the coast and to promote an efficient leasing process. A coordinated effort by federal, state and regional economic development, energy and commerce agencies is needed to develop commitments to purchase offshore wind power. Finally, offshore wind projects must be sited, constructed and operated responsibly in order to avoid and mitigate conflict with local marine life and other uses.

Methodology

Estimates of the benefits of wind energy were obtained by applying national assumptions regarding the amount of pollution or water consumption avoided per megawatt-hour (MWh) of wind energy to estimated wind energy production in 2012 and the amount of wind energy assumed to be produced in 2018 if the United States continues to add wind energy at a pace consistent with recent experience.

Data on annual wind generation (in MWh) for 2012 were obtained from Energy Information Administration, *Electric Power Monthly*, February 2013.

To estimate output from wind facilities in 2018, we assumed the installation of a modest 640 MW of new wind energy capacity in 2013, based on the assumption that approximately half of the 1,280 MW of new wind capacity under construction as of the end of the second quarter of 2013 would be completed by the end of the year.[63] We then assumed that the United States would add onshore wind capacity at a pace equivalent to the average annual addition of wind power capacity from 2007 to 2012, or 8,620 MW—a level of wind energy development well within the historical experience of the United States.

In addition to onshore wind energy, the United States has ample potential to develop wind energy resources in ocean waters and the Great Lakes. To date, the United States does not have any operational offshore wind energy facilities, but several such facilities are in development. Our analysis assumes that the United States will add 3.4 GW of wind energy capacity between 2013 and 2018, based on data from Navigant Consulting, *Offshore Wind Market and Economic Analysis: Annual Market Assessment*, prepared for the U.S. Department of Energy, 22 February 2013.

Table 2. Actual and Assumed Growth in Cumulative U.S. Wind Installations, 1999-2018[64]

Year	Wind Energy Capacity (MW)
1999	2,472
2000	2,539
2001	4,232
2002	4,687
2003	6,350
2004	6,723
2005	9,147
2006	11,575
2007	16,907
2008	25,410
2009	34,863
2010	40,267
2011	46,916
2012	60,007
Estimated onshore additions in 2013	640
Assumed onshore additions, 2014-18	43,100
Assumed offshore additions, 2013-18	3,380
Installed wind capacity at end of 2018	**107,127**

We apportioned new onshore wind energy capacity among the states according to their share of the nation's existing wind power capacity.[65] New offshore wind capacity was apportioned among the states based on the locations of the projects identified in the Navigant Consulting study.

To estimate electricity generation from these capacity additions in each state, we used regional capacity factors based on historical performance data for existing U.S. wind turbines, per Ryan Wiser and Mark Bolinger, *2011 Wind Technologies Market Report*, U.S. Department of Energy, August 2012. Because the state-level data did not include Alaska or Hawaii, we assumed wind projects in those states achieved the national average capacity factor of 33 percent. We assumed that the southeastern states have the same capacity factor as the East. The capacity factor for offshore wind projects is assumed to be 39 percent, based on U.S. Department of Energy, National Energy Technology Laboratory, *Role of Alternative Energy Sources: Wind Technology Assessment*, 30 August 2012.

Technological improvements could lead to significantly increased capacity factors for onshore and offshore wind installations in the near future. To the extent that those improvements develop and are implemented in U.S. wind energy projects, the environmental benefits presented here can be considered conservative estimates.

Estimating Carbon Dioxide Emission Reductions

When a wind turbine generates electricity, it displaces some other source of electricity on the grid. The type of electricity production that is offset by wind depends on several factors: regional variations in the electricity resource mix, the degree to which wind energy offsets new versus existing generation capacity, the relative price of competing forms of electricity generation (including marginal prices), and the way in which wind energy is integrated into the grid, among others.

In this report, we assume that 75 percent of the generation offset by wind energy is in the form of natural gas generation and 25 percent in the form of coal-fired generation. This simple assumption reflects the frequent status of natural gas as a marginal source of generation in much of the country, as well as the recent dominance of natural gas in proposals for new fossil fuel-fired generation capacity. For wind turbines installed through the end of 2012, we assume that the natural gas generation avoided shares the emission characteristics of existing natural gas power plants; for plants installed in 2013 and later years, we assume that wind offsets new natural gas combined cycle power plants.

The use of simplified national assumptions blurs regional variations in the emission reduction benefits of wind energy generation. In its 2012 market report, the American Wind Energy Association estimated that a megawatt-hour of electricity produced from a newly installed wind turbine will offset 1,300 pounds of carbon dioxide pollution on average nationally, but that the reductions would vary by region from as much as 1,630 pounds/MWh to as little as 970 pounds/MWh.[67] Readers should be aware of these potential regional variations in the emission benefits of wind energy and understand that the emission reductions estimated here may vary by as much as +/- 25 percent.

Table 3. Average Capacity Factor, Based on Projects Built from 2004-2010[66]

Region	Average Capacity Factor
East	25%
New England	28%
California	30%
Great Lakes	31%
Northwest	32%
Texas	34%
Mountain	36%
Heartland	37%
Offshore	39%

We calculated a national average carbon dioxide emissions rate for coal and natural gas plants for 2011 based on emissions figures for the electric power industry from U.S. Department of Energy, Energy Information Administration, *State Historical Tables for 2011*, February 2013, and net generation of electricity from U.S. Department of Energy, Energy Information Administration, *Electricity Data Browser*, accessed at www.eia.gov/electricity/data.cfm, 21 October 2013. For new natural gas-fired power plants, we used the emission rate given for a new natural gas combined cycle power plant without carbon capture and storage in U.S. Department of Energy, National Energy Technology Laboratory, *Life Cycle Analysis: Natural Gas Combined Cycle (NGCC) Power Plant*, 30 September 2010.[68]

To put carbon dioxide emission reductions in perspective, we calculated how many passenger vehicles would have to be removed from the road in order to produce comparable savings. Data on vehicle emissions rates is from Environmental Protection Agency, *Clean Energy: Calculations and References*, updated 19 September 2013 and accessed at www.epa.gov/cleanenergy/energy-resources/refs.html.

It is important to note that U.S. power grids cross state lines, such that electricity generated in one state may be consumed in a neighboring state. The emission reductions attributed to each state in this report reflect the emissions impact of wind power produced within each state.

Estimating Avoided Water Consumption

We estimated water savings using freshwater consumption rates in coal and natural gas combined cycle power plants from U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, July 2008. We used the same assumption as for carbon dioxide savings that 75 percent of displaced generation is from natural gas power plants and 25 percent is from coal plants, with water consumption for combined cycle plants used to calculate savings for both existing and future wind power capacity. The U.S. DOE study used national estimates of water consumption due to the lack of regional variation in water consumption patterns among specific technologies, and used the same figures for current and future generation technologies.

In this report, we present data on water *consumption* by power plants, which is the amount of water lost to a watershed (usually through evaporation) as a result of power plant operation. We do not present data on water *withdrawals* for power plant operations. Withdrawals are also a critical measure of power plants' environmental impact as high levels of water withdrawals can have significant impacts on the environment and wildlife. By reducing the need for fossil fuel-fired power plants, wind energy can also reduce the amount of water withdrawn for power plant cooling.

We calculated the number of individuals whose domestic water needs could be met with this amount of saved water. We obtained state-level per capita domestic water use from Joan Kenny et al., *Estimated Use of Water in the United States in 2005*, U.S. Geological Survey, 2009.

As with estimates of the carbon dioxide emission benefits of wind power, estimates of water savings based on national averages may overstate or understate water savings experienced in a particular state, depending on the specific mix of electricity generation that is avoided through the use of wind energy.

Estimating Avoided Emissions of Nitrogen Oxides and Sulfur Dioxide

We also estimated avoided emissions of nitrogen oxides (NO_x) and sulfur dioxide (SO_2) by multiplying electricity generation from wind power by an annual emissions rate for each pollutant. We created

an average annual emission rate for each pollutant assuming that 25 percent of the electricity displaced by existing wind generation would be from existing coal plants, and 75 percent from natural gas power plants. As with our estimates of carbon dioxide emission reductions, we assumed that wind turbines built through the end of 2012 offset emissions from natural gas-fired power plants at a rate characteristic of the existing generation fleet, while new wind turbines offset emissions at a rate characteristic of new natural gas combined cycle power plants.

We calculated a national average emissions rate for coal and natural gas plants for 2011 based on emissions figures for the electric power industry from U.S. Department of Energy, Energy Information Administration, *State Historical Tables for 2011*, February 2013, and net generation of electricity from U.S. Department of Energy, Energy Information Administration, *Electricity Data Browser*, accessed at www.eia.gov/electricity/data.cfm, 21 October 2013. For new natural gas-fired power plants, we used the emission rate given for a new natural gas combined cycle power plant without carbon capture and storage in U.S. Department of Energy, National Energy Technology Laboratory, *Life Cycle Analysis: Natural Gas Combined Cycle (NGCC) Power Plant*, 30 September 2010.[69]

As with the other estimates of environmental impacts in this report, reductions in nitrogen oxide and sulfur dioxide may vary by region depending on the specific characteristics of the electric grid in those areas, as well as regulatory limits on pollution from power plant smokestacks.

SOUND AND SHADOW FLICKER

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Wind turbines and human health

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The association between wind turbines and health effects is highly debated. Some argue that reported health effects are related to wind turbine operation [electromagnetic fields (EMF), shadow flicker, audible noise, low-frequency noise, infrasound]. Others suggest that when turbines are sited correctly, effects are more likely attributable to a number of subjective variables that result in an annoyed/stressed state. In this review, we provide a bibliographic-like summary and analysis of the science around this issue specifically in terms of noise (including audible, low-frequency noise, and infrasound), EMF, and shadow flicker. Now there are roughly 60 scientific peer-reviewed articles on this issue. The available scientific evidence suggests that EMF, shadow flicker, low-frequency noise, and infrasound from wind turbines are not likely to affect human health; some studies have found that audible noise from wind turbines can be annoying to some. Annoyance may be associated with some self-reported health effects (e.g., sleep disturbance) especially at sound pressure levels >40 dB(A). Because environmental noise above certain levels is a recognized factor in a number of health issues, siting restrictions have been implemented in many jurisdictions to limit noise exposure. These setbacks should help alleviate annoyance from noise. Subjective variables (attitudes and expectations) are also linked to annoyance and have the potential to facilitate other health complaints via the nocebo effect. Therefore, it is possible that a segment of the population may remain annoyed (or report other health impacts) even when noise limits are enforced. Based on the findings and scientific merit of the available studies, the weight of evidence suggests that when sited properly, wind turbines are not related to adverse health. Stemming from this review, we provide a number of recommended best practices for wind turbine development in the context of human health.

Keywords: wind turbines, human health, noise, electromagnetic fields, annoyance, infrasound, low-frequency noise, shadow flicker

INTRODUCTION

Wind power has been harnessed as a source of energy around the world for decades. Reliance on this form of energy is increasing. In 1996, the global cumulative installed wind power capacity was 6,100 MW; in 2011, that value had grown to 238,126 MW and at the end of 2013 it was 318,137 MW (1). While public attitude is generally overwhelmingly in favor of wind energy, this support does not always translate into local acceptance of projects by all involved (2). Opposition groups point to a number of issues concerning wind turbines, and possible effects on human health is one of the most commonly discussed. Indeed, a small proportion of people that live near wind turbines have reported adverse health effects such as (but not limited to) ringing in ears, headaches, lack of concentration, vertigo, and sleep disruption that they attribute to the wind turbines. This collection of effects has received the colloquial name "Wind Turbine Syndrome" (3).

The reason for the self-reported health effects is highly debated and information fueling this debate is found primarily in four sources: peer-reviewed studies published in scientific journals, government agency reports, legal proceedings, and the popular literature and internet. Some argue that reported health effects are related wind turbine operational effects [e.g., electromagnetic fields (EMF), shadow flicker from rotor blades, audible noise, low-frequency noise (LFN) and infrasound]; others suggest that when turbines are sited correctly, reported effects are more likely attributable to a number of subjective variables, including nocebo responses, where the etiology of the self-reported effect is in beliefs and expectations rather than a physiologically harmful entity (4–8). In 2011, Knopper and Ollson (9) published a review that contrasted the human health effects that had been purported to be caused by wind turbines in popular literature sources with what had been reported in the peer-reviewed scientific literature as well as by various government agencies. At that time, only 15 articles in the peer-reviewed scientific literature that specifically addressed issues related to human health and wind turbines were available [i.e., (4, 5, 10–22)].

Based on their review, Knopper and Ollson (9) concluded that although there was evidence to suggest that wind turbines can be a source of annoyance to some people, there was no evidence demonstrating a direct causal link between living in proximity to wind turbines and more serious physiological health effects. Furthermore, although annoyance has been statistically significantly

associated with wind turbine noise [especially at sound pressure levels >40 dB(A)], a convincing body of evidence exists to show that annoyance is more strongly related to visual cues and attitude than to wind turbine noise itself. In particular, this was highlighted by the fact that people who benefit economically from wind turbines (e.g., those who have leased their property to wind farm developers) reported significantly lower levels of annoyance than those who received no economic benefit, despite increased proximity to the turbines and exposure to similar (or louder) sound levels.

In the years following the publication of Knopper and Ollson (9), the debate surrounding the relationship between wind turbines and human health has continued, both in the public and within the scientific community. In this review, we provide a bibliographic-like summary and analysis of the science around this issue specifically in terms of noise (including audible, LFN, and infrasound), EMF, and shadow flicker. Stemming from this review, we provide weight of evidence conclusions and a number of best practices for wind turbine development in the context of human health.

METHODS

The authors worked with a professional Health Sciences Information Specialist to develop a search strategy of the literature. Combinations of key words (i.e., annoyance, noise, environmental change, sleep disturbance, epilepsy, stress, health effect(s), wind farm(s), infrasound, wind turbines(s), LFN, EMF, wind turbine syndrome, neighborhood change) were entered into PubMed, the Thomson Reuters Web of Knowledge^{SM} and Google. No date restrictions were entered and literature was assessed up to the submission date of this manuscript (April 2014). The review was conducted in the spirit of the evaluation process outlined in the Cochrane Handbook for Systematic Reviews of Interventions.

As of the publication date of this review, there are close to 60 scientific peer-reviewed articles on the topic. Sources of information other than peer-reviewed scientific literature (e.g., websites, opinion pieces, conference proceedings, unpublished documents) were purposely excluded in this review because they are often unreliable and provide information that is typically anecdotal in nature or not traceable to scientific sources. A general summary, and key words of the articles reviewed herein, are presented in **Table 1**. These summaries provide results as they were reported by the authors of the articles and are without secondary interpretation.

Through the systematic review process, it was evident that there was significant variability in both the measures of exposure (i.e., proximity to turbines, field noise measures, lab noise measures, or magnetic field measurements) and the health outcomes examined (i.e., annoyance, sleep scores, and various quality of life metrics). The methodological heterogeneity in study designs across the selected health-based investigations inhibited a quantitative combination of results. In other words, meta-analytic methods were not appropriate for this updated systematic review of the literature on wind turbine and health effect. Rather qualitative interpretation is provided.

RESULTS

OVERALL NOISE

Knopper and Ollson (9) reviewed a number of studies that examined the noise levels produced by wind turbines, perception of wind turbine noise, and/or responses to wind turbine noise [e.g., (4, 5, 10, 12, 13, 15–18, 21)]. The results of more recent studies that investigated wind turbine noise with respect to potential human health effects are summarized below in chronological order of publication.

Shepherd et al. (23): Shepherd et al. reported on a cross-sectional study comparing health-related quality of life (HRQOL) of people living in proximity (i.e., <2 km) to a wind farm to a control group living >8 km away from the nearest wind farm. It involved self-administered questionnaires that included the World Health Organization (WHO) quality of life scale, in semi-rural New Zealand. The turbine group was drawn from residents of 56 homes in South Makara Valley, all within 2 km of a wind turbine. General outdoor noise levels in the area, obtained from a conference proceeding by Botha (53), were reported to range from 24 to 54 dB(A). The comparison group was taken from 250 homes in a geographically and socioeconomically matched area, at least 8 km from any wind farm in the region. General outdoor noise levels for the comparison group were not reported. The questionnaire was named the "*2010 Well-being and Neighborhood Survey*" in order to mask the true intent of the study and reduce bias against wind turbines. This is similar to the work of Pedersen in Europe, in that the surveys were not explicitly about wind turbines. Response rates were 34% from the Turbine group (number of participants $n = 39$) and 32% from the Comparison group ($n = 158$).

Overall, Shepherd et al. reported statistically worse ($p < 0.05$) scores in the Turbine group for physical HRQOL, environmental QOL and HRQOL in general. There was no statistical difference in social or psychological scores. Based on these results, the authors concluded that "utility-scale" wind energy generation was not without adverse health impacts on nearby residents and suggested setback distances need to be >2 km in hilly terrain. However, there are a number of limitations in this study that undermine the conclusion stated above. One key concern is that the results were based on only a limited number of participants ($n = 39$) for the Turbine group. In comparison, the survey datasets compiled in Sweden and the Netherlands by Pedersen and Persson Waye (4, 5) and Pedersen et al. (17), respectively, involved a total of 1,755 respondents overall. In these surveys, the only response found to be significantly related to A-weighted wind turbine noise exposure was annoyance, even though a number of physiological and psychological variables were also investigated. In addition, Shepherd et al. did not discuss the impact of participants' attitudes or visual cues that may have influenced the reports of decreased HRQOL. Given that other studies have indicated that annoyance was more closely related to visual cues and attitude, this could provide further explanation of why overall HRQOL scores were lower in the Turbine group. Presumably all residents within 2 km of a turbine would be able to see one, or more, of the turbines. Furthermore, although it was implied in the title of the article that noise from wind turbines was causing the observed effects, the study did not include either measured or estimated wind turbine noise exposure values for the individual survey respondents. Therefore, they were unable to demonstrate a dose–response relationship between the observed responses and exposure to wind turbine noise. In light of this, as recognized by Shepherd et al. (23), it is possible that the observed effects were driven by other causes such as conflicts between the community and the wind farm developers rather than a direct

Table 1 | General summary of reviewed articles.

General topic	Authors	Source	Key words	General summary
Audible noise	Shepherd et al. (23)	Noise and Health	Health-related quality of life (HRQOL)	Cross-sectional study involving questionnaires about quality of life living near and away from turbines. Statistically significant differences were noted in some HRQOL scores; residents within 2 km of a turbine reporting lower overall quality of life, physical quality of life, and environmental quality of life
	Janssen et al. (24)	Journal of the Acoustical Society of America	Annoyance, economic benefit, sensitivity, visual cues	Expanded on the datasets collected by Pedersen and Persson Waye (4, 5) and Pedersen et al. (17) in Sweden and the Netherlands. Authors evaluated self-reported annoyance indoors and outdoors compared to sound levels (Lden) from wind turbines. Like the authors before them who relied on these datasets, found that annoyance decreased with economic benefit and may have increased with noise sensitivity, visibility, and age. In comparison to other sources of environmental noise, annoyance due to wind turbine noise was found at relatively low noise exposure levels
	Verheijen et al. (25)	Science of the Total Environment	Annoyance, noise limits	Objective was to assess proposed Dutch standards for wind turbine noise and consequences for people and feasibility of meeting energy policy targets. Authors used a combination of audible and low-frequency noise models and functions to predict existing level of severely annoyed people living around existing wind turbines in the Netherlands. Found that at 45 dB(Lden) severe annoyance due to low-frequency noise unlikely; suggested that this noise limit is suitable as a trade-off between the need for protection against noise annoyance and the feasibility of national targets for renewable energy
	Bakker et al. (26)	Science of the Total Environment	Annoyance, distress, economic benefit, sleep disturbance	A dose–response relationship was found between immission levels of wind turbine sound and self-reported noise annoyance. Sound exposure was also related to sleep disturbance and psychological distress among those who reported that they could hear the sound, however not directly but with noise annoyance. Respondents living in areas with other background sounds were less affected than respondents in quiet areas. Found that people, animals, traffic and mechanical sounds were more often identified as a source of sleep disturbance than wind turbines
	Nissenbaum et al. (27)	Noise and Health	Epworth Sleepiness Score (ESS), Pittsburgh Sleep Quality Index (PSQI), SF36v2	Purpose of the investigations was to determine the relationship between reported adverse health effects and wind turbines among residents of two rural communities. Participants living 375–1,400 m and 3.3–6.6 km were given questionnaires to obtain data about sleep quality, daytime sleepiness and general physical and mental health. Authors reported that when compared to people living further away than 1.4 km from wind turbines, those people living within 1.4 km of wind turbines had worse sleep, were sleepier during the day and had worse mental health scores
	Ollson et al. (28)	Noise and Health	Rebuttal to Nissenbaum et al. (27)	Suggested that Nissenbaum et al. (27) extended their conclusions and discussion beyond the statistical findings of their study and that they did not demonstrated a statistical link between wind turbines – distance – sleep quality – sleepiness and health. In fact, their own statistical findings suggest that although, scores may be statistically different between near and far groups for sleep quality and sleepiness, they are no different than those reported in the general population. The claims of causation by the authors (i.e., wind turbine noise) for negative scores are not supported by their data
	Barnard (29)	Noise and Health	Rebuttal to Nissenbaum et al. (27)	Pointed out a number of problems with Nissenbaum et al. (27) study and suggested that data presented do not justify the very strong conclusions reached by the authors

(Continued)

Table 1 | Continued

General topic	Authors	Source	Key words	General summary
Audible noise (continued)	Mroczek et al. (30)	Annals of Agricultural and Environmental Medicine	SF-36, Visual Analog Scale (VAS)	Purpose of study was to assess how people's quality of life is affected by the close proximity of wind farms. Authors found that close proximity of wind farms does not result in the worsening of the quality of life based on the Norwegian version of the SF-36 General Health Questionnaire, the Visual Analog Scale (VAS) for health assessment, and original questions
	Taylor et al. (31)	Personality and Individual Differences	Personality traits	Study examined the influence of negative oriented personality (NOP) traits on the effects of wind turbine noise and reporting on non-specific symptoms (NSS). Results of the study showed that while calculated actual wind turbine noise did not predict reported symptoms, perceived noise did
	Evans and Cooper (32)	Acoustics Australia	Predicted and measured noise levels	A comparison of predicted noise levels from four commonly applied prediction methods against measured noise levels from six operational wind farms (at 13 locations) in accordance with the applicable guidelines in South Australia. Results indicate that the methods typically over-predicted wind farm noise levels but that the degree of conservatism appeared to depend on the topography between the wind turbines and the measurement location
	Maffei et al. (33)	International Journal of Environmental Research and Public Health	Visual cues, perception	Investigated the effects of the visual impact of wind turbines on the perception of noise. Found distance was a strong predictor of an individual's reaction to the wind farm; data showed that increased distance resulted in a more positive general evaluation of the scenario and decreased perceived loudness, noise annoyance, and stress caused by sound. Found the color of the wind turbines (base and blade stripes) impacted an individuals' perception of noise
	Van Renterghem et al. (34)	Science of the Total Environment	Annoyance, attitude, laboratory experiment, visual cues	Conducted a two-stage listening experiment to assess annoyance, recognition, and detection of noise from a single wind turbine. Results support the hypothesis that non-noise variables, such as attitude and visual cues, likely contributed to the observation that people living near wind turbines (who do not receive an economic benefit from the turbines) report higher levels of annoyance at lower sound pressure levels than would be predicted for other community noise sources
	Baxter et al. (35)	Energy Policy	Risk perception, economic benefit, community conflict, policy	Conducted a study to investigate the role of health risk perception, economic benefit, and community conflict on wind turbine policy. Two communities were assessed: one located in proximity to two operating wind farms and a control community without turbines. Authors found that residents from the community with operational wind energy projects were more supportive of wind turbines than residents in the area without turbines
	Chapman et al. (6)	PLoS One	Psychogenic effects, nocebo, community complaints	Provided an overview of the growing body of literature supporting the notion that the attribution of symptoms and disease to wind turbine exposure is a modern health worry. Suggested that nocebo effects likely play an important role in the observed increase in wind farm-related health complaints. Suggested that reported historical and geographical variations in complaints were consistent with "communicated diseases" with nocebo effects likely to play an important role in the etiology of complaints rather than direct effects from turbines
	Whitfield Aslund et al. (36)	Energy Policy	Predicted annoyance, modeling	Used previously reported dose–response relationships between wind turbine noise and annoyance to predict the level of community noise annoyance that may occur in the province of Ontario. The results of this analysis indicate that the current wind turbine noise restrictions in Ontario will limit community exposure to wind turbine related noise such that levels of annoyance are unlikely to exceed previously established background levels of noise-related annoyance from other common noise sources

(Continued)

Table 1 | Continued

General topic	Authors	Source	Key words	General summary
Low-frequency noise and infrasound	Møller and Pedersen (37)	Journal of the Acoustical Society of America	Annoyance, insulation, indoor sound levels	Conducted a low-frequency noise study from four large turbines (>2 MW) and 44 other small and large turbines (7 > 2 MW and 37 < 2 MW). Low-frequency sound insulation was measured for 10 rooms under normal living conditions in houses exposed to low-frequency noise. Concluded that the spectrum of wind turbine noise moves down in frequency with increasing turbine size. Suggested that the low-frequency part of the noise spectrum plays an important role in the noise at neighboring properties. They hypothesized that if the noise from the investigated large turbines had an outdoor level of 44 dB(A) there was a risk that a substantial proportion of the residents would be annoyed by low-frequency noise, even indoors
	Bolin et al. (38)	Environmental Research Letters	Health effects, review, turbulence	Conducted a literature review over a 6-month period ending April 2011 into the potential health effects related to infrasound and low-frequency noise exposure surrounding wind turbines. Concluded that empirical support was lacking for claims that low-frequency noise and infrasound cause serious health affects in the form of "vibroacoustic disease," "wind turbine syndrome," or harmful effects on the inner ear
	Rand et al. (39)	Bulletin of Science, Technology and Society	Indoor sound levels, health effects, acute effects	Studies took place over a 2-day period inside a home where people were self-reporting serious adverse health effects. Authors reported on wind speed at hub of turbine, dB(A) and dB(G) filtering indoors and outdoors. Reported on acute effects
	Ambrose et al. (40)	Bulletin of Science, Technology and Society		
	Turnbull et al. (41)	Acoustics Australia	Underground measurement, comparative study	Developed an underground technique to measure infrasound. Measured infrasound at two Australian wind farms as well as in the vicinities of a beach, a coastal cliff, the city of Adelaide, and a power station. Reported that the measured levels at wind farms below the audibility threshold and similar to that of urban and coastal environments and near other engineered noise sources. Level of infrasound from wind farms at 360 and 85 m [61 and 72 dB(G), respectively] was comparable to that observed at a distance of 25 m from ocean waves [75 dB(G)]
	Crichton et al. (7)	Health Psychology	Negative expectations, symptom reporting, laboratory experiment	Examined the possibility that expectations of negative health effects from exposure to infrasound promote symptom reporting using a sham controlled, double-blind provocation study. Participants in the high-expectancy group reported significant increases in the number and intensity of symptoms experienced during exposure to both infrasound and sham infrasound. Conversely, there were no symptomatic changes in the low-expectancy group
	Crichton et al. (8)	Health Psychology	Negative and positive expectations, symptom reporting, laboratory experiment	Authors investigated how positive expectations can produce a reduction in symptoms. Expectations were found to significantly alter symptom reporting: participants who were primed with negative expectations became more symptomatic over time, suggesting that their experiences during the first exposure session reinforced expectations and led to heightened symptomatic experiences in subsequent sessions

(Continued)

Table 1 | Continued

General topic	Authors	Source	Key words	General summary
Electromagnetic fields	Havas and Colling (42)	Bulletin of Science, Technology and Society	Poor power quality, ground current, electrical hypersensitivity	Authors hypothesized that symptoms of some living near wind turbines could be caused by electromagnetic waves in the form of poor power quality (dirty electricity) and ground current resulting in health effects in those that are electrically hypersensitive. Indicated that individuals reacted differently to both sound and electromagnetic waves and this could explain why not everyone experienced the same health effects living near turbines
	Israel et al. (43)	Environmentalist	Vibration measurement, noise, risk	Conducted EMF, sound, and vibration measurements at wind energy parks in Bulgaria. Concluded that EMF levels were not of concern from wind farm
	McCallum et al. (44)	Environmental Health	Variable distances and wind, residential measures	Magnetic field measurements were collected in the proximity of 15 wind turbines, two substations, buried and overhead collector and transmission lines and nearby homes. Results suggest there is nothing unique to wind farms with respect to EMF exposure; in fact, magnetic field levels in the vicinity of wind turbines were lower than those produced by many common household electrical devices and were well below any existing regulatory guidelines with respect to human health
Review articles, editorials and social commentaries	Bulletin of Science, Technology and Society (BSTS) Special Edition	Bulletin of Science, Technology and Society	Various authors, health effects, social commentary, opinion pieces	Special edition made up of nine articles devoted entirely to wind farms and potential health effects. Many of the articles in the special edition were written as opinion pieces or social commentaries
	Hanning and Evans (45)	British Medical Journal	Sleep disturbance	Purpose was to opine on the relationship between wind turbines noise and health effects. Suggested that a large body of evidence exists to suggest that wind turbines disturb sleep and impair health at distances and external noise levels that are permitted in most jurisdictions
	Chapman (46)	British Medical Journal	Weight of evidence	In a rebuttal to Hanning and Evans (45) Chapman points to 17 independent reviews of the literature around wind turbines and human health that contrast the opinion of Hanning and Evans
	Farboud et al. (47)	Journal of Laryngology and Otology	Low-frequency noise (LFN), infrasound (IS), inner ear physiology, wind turbine syndrome	Conducted a literature search for articles published within the last 10 years, using the PubMed database and the Google Scholar search engine, to look at the effects of low-frequency noise and infrasound. Suggested the evidence available was incomplete and until the physiological effects of LFN and infrasound were fully understood, it was not possible to conclusively state that wind turbines were not causing any of the reported effects
	McCubbin and Sovacool (48)	Energy Policy	Comparative study, natural gas, health, and environmental benefits	Compared the health and environmental benefits of wind power in contrast to natural gas
	Roberts and Roberts (49)	Journal of Environmental Sciences	PubMed-based review, low-frequency noise (LFN), infrasound (IS), health effects	Conducted a summary of the peer-reviewed literature on the research that examined the relationship between human health effects and exposure to low-frequency sound and sound generated from the operation of wind turbines. Concluded that a specific health condition or collection of symptoms has not been documented in the peer-reviewed, published literature that has been classified as a "disease" caused by exposure to sound levels and frequencies generated by the operations of wind turbines

(Continued)

Table 1 | Continued

General topic	Authors	Source	Key words	General summary
Review articles, editorials and social commentaries (continued)	Chapman and St. George (50)	Australian and New Zealand Journal of Public Health	Vibroacoustic disease (VAD); factoid	Investigated the extent to which VAD and its alleged association with wind turbine exposure had received scientific attention, the quality of that association and how the alleged association gained support by wind farms opponent. Based on a structured scientific database and Google search strategy, the authors showed that VAD has received virtually no scientific recognition and that there is no evidence of even rudimentary quality that vibroacoustic disease is associated with or caused by wind turbines. Stated that an implication of this "factoid" – defined as questionable or spurious statements – may have been contributing to nocebo effects among those living near turbines
	Jeffery et al. (51)	Canadian Family Physician	Health effects	Overall goal of these commentary pieces was to provide information to physicians regarding the possible health effects of exposure to noise produced by wind turbines and how these may manifest in patients
	Jeffery et al. (52)	Canadian Journal of Rural Medicine		

result of noise exposure. Based on the limitations discussed above, we consider that the authors' recommendation for a 2 km setback distance was not supported by the evidence presented in this study.

Janssen et al. (24): expanding on the datasets collected by Pedersen and Persson Waye (4, 5) and Pedersen et al. (17) in Sweden and the Netherlands, Janssen et al. evaluated self-reported annoyance indoors and outdoors compared to sound levels (Lden) from wind turbines. To derive the Lden, the authors added a correction factor of 4.7 dB(A) to outdoor A-weighted sound pressure levels from the datasets used in the previous studies. Annoyance in this study was ranked on a 4-point scale: 1 was "not annoyed," 2 was "slightly annoyed," 3 was "rather annoyed," and 4 was "very annoyed." Visual cue ("Can you see a wind turbine from your dwelling or your garden/balcony?"), economic benefit ["Are you a (co)owner of one or more wind turbines?"], and noise sensitivity (on either a 4 or 5 point scale with 1 representing "not sensitive" and 4 or 5 representing "very/extremely sensitive") were also assessed. Like the authors before them who relied on these datasets, Janssen et al. found that annoyance decreased with economic benefit and may have increased with noise sensitivity, visibility, and age. Rates of annoyance indoors from wind turbines to industrial noise from stationary sources and air, road and rail noise were also compared and it was concluded that: "*. . .annoyance due to wind turbine noise is found at relatively low noise exposure levels*" and that "*some similarity is found in the range Lden 40–45 dB between the percentage of annoyed persons by wind turbine noise and aircraft noise.*"

Verheijen et al. (25): the objective of this study was to assess the proposed Dutch protective standards for wind turbine noise, both on consequences for inhabitants and feasibility of meeting energy policy targets. The authors used a combination of audible and LFN models and functions derived by Janssen et al. (24) to predict the existing level of severely annoyed people living around existing wind turbines in the Netherlands. They estimated that there were approximately 1,500 severely annoyed individuals, in a total population of approximately 440,000 living at sound levels of 29 dB(Lden) around wind turbines. The authors reported that: "*For The Netherlands, a socially acceptable percentage of severely annoyed lies around 10%, which can be derived from the existing limits and dose–response functions of railway and road noise. This would result in an acceptable noise reception limit for wind turbines of about 47 to 49 dB.*" The authors decided to examine the feasibility of lowering the limit below 47–49 dB(Lden). They estimated that it may be feasible from a land mass perspective to lower the noise limit to 40 dB(Lden); however, given that lands are often rejected due to reasons other than noise that another value should be selected. They stated "*The percentage of severely annoyed at 45 dB is rated at 5.2% for wind turbine noise, which is well below 10% that corresponds to the existing road and railway traffic noise limits.*" They also determined that, at 45 dB(Lden), severe annoyance effects due to LFN were unlikely and suggested that this noise limit suited as a trade-off between the need for protection against noise annoyance and the feasibility of national targets for renewable energy.

Bakker et al. (26): the purpose of this study was to evaluate the relationship between exposure to the sound of wind turbines and annoyance, self-reported sleep disturbance, and psychological distress of people that live in their vicinity. This investigation relied on survey data, previously reported and discussed by Pedersen et al. (17), collected from 725 residents of the Netherlands living in the vicinity of wind turbines. As reported by Pedersen et al. (17), survey respondents answered questions about environmental factors and road traffic noise (and wind noise) as well as the effect of wind turbines on annoyance, sleep disturbance, and psychological distress.

Bakker et al. differed from Pedersen et al. (17) in that it provided a direct comparison of people who economically benefited from turbines with those who did not, specifically in relation to annoyance. Bakker et al. (26) reported that only 3% of survey respondents receiving economic benefit from wind turbines reported being "rather annoyed" or "very annoyed" by wind turbine noise when outdoors, while none reported being rather or very annoyed by wind turbine noise when indoors. In comparison,

the proportions of survey respondents who did not receive an economic benefit who reported being rather or very annoyed indoors and outdoors were 12 and 8%, respectively, even though they were exposed to significantly lower levels of wind turbine sound.

What is more, Bakker et al. also compared sound-related sources of sleep disturbance in rural and urban areas in respondents who did not benefit economically from wind turbines. They found that people, animals, traffic, and mechanical sounds were more often identified as a source of sleep disturbance than wind turbines. In fact, in rural areas, only 6% of people identified wind turbines as the sound source of sleep disturbance compared to 11.7% for people/animals and 12.5% for traffic/mechanical sounds. In urban areas, only 3.8% of people identified wind turbines as the sound source of sleep disturbance compared to 14.4% for people/animals and 16.9% for traffic/mechanical sounds.

Nissenbaum et al. (27), Ollson et al. (28), and Barnard (29): the stated purpose of the investigations conducted by Nissenbaum et al. was to determine the relationship between reported adverse health effects and wind turbines among residents of two rural communities. Participants living 375–1,400 m and 3.3–6.6 km were given questionnaires to obtain data about sleep quality [using the Pittsburgh Sleep Quality Index (PSQI)], daytime sleepiness [using the Epworth Sleepiness Score (ESS)], and general physical and mental health (MH) (using the SF36v2 health survey). Overall, the authors reported that when compared to people living further away than 1.4 km from wind turbines, those people living within 1.4 km of wind turbines had worse sleep, were sleepier during the day, and had worse MH scores. Based on these findings the authors concluded that: "*. . .the noise emissions of IWTs disturbed the sleep and caused daytime sleepiness and impaired mental health in residents living within 1.4 km of the two IWT installations studied.*"

In a subsequent issue of Noise and Health, two letters to the editor were published that were critical of this study and its conclusions (28, 29). In particular, the letter from Barnard (29) criticized the statistical analysis in Nissenbaum et al. (27), which stated that there was a "strong" dose–response relationship between distance to the nearest wind turbine and both the "PSQI" and the "Epworth Sleepiness Scale." Barnard stated: "*I cannot see how this is justified, given the presented data. In contrast to the conclusions, Figure 1 and Figure 2 in the paper. . . show a very weak dose-response, if there is one at all. The near horizontal 'curve fits' and large amount of 'data scatter' are indications of the weak relationship between sleep quality and turbine distance. The authors seem to use a low P value as a support for the hypothesis that sleep disturbance is related to turbine distance. A better interpretation of the P value related to a near horizontal line fit would be that it suggests a high probability of a weak-dose response. Correlation coefficients are not given, but should have been given, to indicate the quality of the curve fits.*" Ollson et al. (28) pointed out that Nissenbaum et al. extended their conclusions and discussion beyond the statistical findings of their study. They stated "*We believe that they have not demonstrated a statistical link between wind turbines – distance – sleep quality – sleepiness and health. In fact, their own statistical findings suggest that although, scores may be statistically different between near and far groups for sleep quality and sleepiness, they are not different than those reported in the general population. The claims of causation by the authors (i.e., wind turbine noise) for negative MCS scores are not supported by their data. This work is exploratory in nature and should not be used to set definitive setback guidelines for wind-turbine installations.*"

Mroczek et al. (30): Mroczek et al. published the results of a study conducted in 2010 that evaluated the impact of living in close proximity to wind turbines on an individual's perceived quality of life. The study group consisted of 1,277 randomly selected Polish adults (703 women and 574 men) living in the vicinity of wind farms. The different distance (house to turbine) groups were: <700 m, from 700 to 1000 m, from 1,000 to 1,500 m, and >1,500 m. The quality of life was measured using the Norwegian version of the SF-36 General Health (GH) Questionnaire, the Visual Analog Scale (VAS) for health assessment, and some original questions about approximate distance to wind farm, age, gender, education, and profession. The SF-36 (Short Form 36) Questionnaire consists of 36 questions divided into 8 subscales: physical functioning (PF), role functioning physical (RP), bodily pain (BP), GH, vitality (V), social functioning (SF), role functioning emotional (RE), MH, and one additional question regarding health changes.

According to the authors "*The respondents assessed their health through answering questions included in the SF-36 and VAS. They were asked to mark the point corresponding with their well-being on the level from 0 to 100, where 0 denoted the worst possible state of health and 100 – excellent health.*" The results showed that regardless of the distance from the wind farm (i.e., from <700 to >1,500 m) respondents ranked their PF scores as highest out of all of the quality of life components. Overall, people living closest to wind farms assessed their quality of life as higher than those living in more distant areas. The scores for the MH component, GH, SF, and RE were highest in the group living closest to the wind farms and lowest by those living greater than 1.5 km away. The authors noted that there may have been confounding factors that contributed to the observed results (e.g., economic factors). Since other studies have shown links between self-reported health status, proximity to wind turbines and the direct influence of economic benefit on levels of annoyance [e.g., (17, 26)], these major confounding factors also need to be considered when interpreting the results of the Mroczek et al. study on quality of life and proximity to wind turbines.

Taylor et al. (31): this study examined the influence of negative oriented personality (NOP) traits on the effects of wind turbine noise and reporting on non-specific symptoms (NSS). The study was conducted based on the hypothesis that the public has become increasingly concerned with attributing NSS to environmental features (e.g., wind turbines). The study focused on three NOP traits in particular: neuroticism (N), negative affect (NA), and frustration intolerance (FI). The authors noted that previous research has demonstrated that individuals with high N and NA typically evaluate their environment more negatively. Furthermore, FI may have impacted the way an individual perceived and evaluated environmental factors from an inability to bear or cope with perceived negative emotions, thoughts and events. A survey was mailed out to 1,270 households within 500 m of eight 0.6 kW turbine installations and within 1 km of four 5 kW turbines in two cities in the U.K. Individuals within the household (>18 years old) could anonymously complete the survey and mail the results back or submit them online. In total, 138 completed surveys were

returned. Actual sound levels were calculated for those households who completed the survey, and participants were asked to describe the perceived noise, including the type of noise (e.g., swooshing, whistling, buzzing), frequency, and loudness (based on a 0–4 ranking scale). Participants were also asked a series of questions to determine the level of NOP traits and related health/symptom reporting information.

The results of the study showed that while calculated actual wind turbine noise did not predict reported symptoms, perceived noise did. Specifically: "*. . .for those higher in NOP traits, there was a stronger link between perceived noise and symptom reporting. There was however, no relationship between calculated actual noise from the turbine and participants attitude to wind turbines. This means that those who had a more negative attitude to wind turbines perceived more noise from the turbine, but this effect was not simply due to individuals being able to actually hear the noise more.*"

Evans and Cooper (32): in their paper called "Comparison of predicted and measured wind farm noise levels and implications for assessments of new wind farms," Evans and Cooper present a comparison of predicted noise levels from four commonly applied prediction methods against measured noise levels from six operational wind farms (conducted at 13 locations) in accordance with the applicable guidelines in South Australia. The results indicate that the methods typically over-predicted wind farm noise levels but that the degree of conservatism appeared to depend on the topography between the wind turbines and the measurement location. Briefly, Evans and Cooper found that the commonly used ISO 9613-2 model (with completely reflective ground) and the CONCAWE model generally over-predicted noise levels by 3–6 dB(A), but the amount of over-prediction was related to the topography (i.e., relatively flat topography or a steady slope from the turbines). However, at sites where there was a significant concave slope from the turbines down to the measurement sites, these commonly used prediction methods were typically accurate, with the potential of marginal under-prediction in some cases (when ISO 9613-2 used 50% absorptive ground).

A requirement of many regulatory agencies is that noise modeling be conducted by developers prior to the construction of wind turbines. A common criticism of this approach is that modeled values are not representative of actual noise from operational wind farms. Evans and Cooper's findings show that this is not the case, but caution about the role of topography.

Maffei et al. (33): despite the fact that wind farms are represented as environmentally friendly projects, wind turbines are viewed by some as visual and audible intruders that spoil the landscape and generate noise. Consequently, Maffei et al. (33) conducted a study investigating the effects of the visual impact of wind turbines on the perception of noise. The study consisted of 64 participants (34 males, 30 females) who resided in either urban or rural areas. Participants were asked to fill out a questionnaire to obtain information regarding age, gender, education, and local neighborhood characteristics. A number of statements were then submitted to the participants where they were asked to respond based on a 100-point Likert scale ranging from "disagree strongly" to "agree strongly." The statements were based on personal views about green energy, wind turbines, noise, and other related subject matter. Subsequently, a virtual reality scenario was created to emulate the visual impact of a wind farm on a rural landscape and included an audio component recorded from a 16 turbine wind farm in Frigento, Italy. In total, three factors were manipulated in the experiment: distance from the wind farm (150, 250, and 500 m); the number of wind turbines (1, 3, and 6); the color of the base of the turbine and any stripes on the blades (white, red, brown, green). Each participant was asked to view all of the scenarios using a 3D visor and asked to respond to a number of questions pertaining to perceived loudness, sound pleasantness, noise annoyance, sound stress, sound tranquility, and visual pleasantness.

The results found that distance was a strong predictor of an individual's reaction to the wind farm. In particular, the data showed that increased distance resulted in a more positive general evaluation of the scenario and decreased perceived loudness, noise annoyance, and stress caused by sound. Additionally, the authors found that the color of the wind turbines (base and blade stripes) impacted an individuals' perception of noise. Generally, white and green turbines were preferred to brown and red ones. Specifically, green turbines scored the highest since they were perceived as being the "most integrated" into the landscape. The authors concluded that their results confirmed the interconnectedness between auditory and visual components of individual perception.

Van Renterghem et al. (34): Van Renterghem et al. (34) conducted a two-stage listening experiment to assess annoyance, recognition, and detection of noise from a single wind turbine. A total of 50 participants with "normal" hearing abilities participated in the experiment and were classified as having a positive to neutral attitude toward renewable energy. *In situ* recordings made at close distance (30 m downwind) from a 1.8 MW turbine operating at 22 rotations per minute (rpm) were mixed with road traffic noise and processed to simulate indoor sound pressure levels at 40 dB(LAeq). In the first stage, where participants were unaware of the true purpose of the experiment, samples were played during a quiet leisure activity. Under these conditions (i.e., when people were unaware of the different sources of noise), pure wind turbine noise produced similar annoyance ratings as unmixed highway noise at the same equivalent level, while annoyance from local road traffic was significantly higher. These results supported the hypothesis that non-noise variables, such as attitude and visual cues, likely contributed significantly to the observation that people living near wind turbines (who do not receive an economic benefit from the turbines) report higher levels of annoyance at lower sound pressure levels than would be predicted for other community noise sources [e.g., (17, 24)].

In the second stage of the Van Renterghem et al. (34) study, participants were allowed to listen to a recording of unmixed wind turbine sound [at 40 dB(A)] for 30 s in order to familiarize themselves with the sound. After this, they listened to 10 sets of paired sound samples; one of which contained unmixed road traffic noise and the other that contained wind turbine noise mixed with road traffic at signal-to-noise ratios varying between −30 dB(A) and +10 dB(A). For each pair, participants were asked to identify which of the two samples contained the wind turbine noise. The detection of wind turbine noise in the presence of highway noise was found a "signal-to-noise" ratio as low as −23 dB(A). This demonstrated that once the subject was familiar with wind turbine noise, it could

easily be detected even in the presence of highway traffic noise. This could also help explain the increased rates of noise annoyance at home reported by Pedersen et al. (17) and Janssen et al. (24) since residents would be familiar with the sound and be able to discern it if they listened for it when primed by visual cues. Overall, the findings support the idea that noticing the sound could be an important aspect of wind turbine noise annoyance. Awareness of the source and recognition of the wind turbine sound was also linked to higher levels of annoyance. Van Renterghem et al. noted that: "*The experiment reported in this paper supports the hypothesis that previous observations, reporting that retrospective annoyance for wind turbine noise is higher than that for highway noise at the same equivalent noise level, is grounded in higher level appraisal, emotional, and/or cognitive processes. In particular, it was observed that wind turbine noise is not so different from traffic noise when it is not known beforehand.*"

Baxter et al. (35): in 2010, Baxter and colleagues conducted a study to investigate the role of health risk perception, economic benefit, and community conflict on wind turbine policy. The study, published in 2013, had two parts: a literature review and quantitative survey meant to determine perceptions of wind turbines and how they are linked to support or opposition to wind turbines in the community. Two communities were assessed: one located in proximity to two operating wind farms and a control community without turbines. Overall, the authors found that residents from the community with operational wind energy projects (which were introduced prior to the *Green Energy Act* in Ontario) were more supportive of wind turbines than residents in the area without turbines (78 vs. 29%, with "support" defined as agreeing to vote in favor of local turbines). The authors also reported that residents in the turbine community were more accepting of turbine esthetics than people in the control community and less worried about health impacts, this despite the fact that the wind farms in the "case" group were in some cases closer to homes than currently permitted.

Baxter et al. indicated that the lack of support in the control community could have been due to political lobbying during the provincial election, where one candidate suggested a moratorium on wind turbine as part of their campaign. The authors also highlighted the role of health risk perception (which seemed linked to political lobbying) as a variable leading to the lack of support. The finding that "*Our study highlights the need to add health risk perception to the agenda for social research on turbines*" is valid, albeit dated in the Ontario context, since an integral part of any wind development project in Ontario is public consultation with wind turbines and health as a fundamental component. These findings supported the idea that perception of health risks is heavily impacted by expectation, media coverage, and that "hands on experience" could serve to increase familiarity and decrease concerns.

Chapman et al. (6): the authors provided an overview of the growing body of literature supporting the notion that the attribution of symptoms and disease to wind turbine exposure is a modern health worry. Chapman et al. also suggested that nocebo effects likely play an important role in the observed increase in wind farm-related health complaints. By evaluating records of complaints from wind farm companies about noise or health from residents living near 51 wind farms across Australia, two theories about the etiology of complaints were tested: one being direct effects from turbines and the other being "psychogenic" effects brought on by nocebo effects.

Chapman et al. found a number of historical and geographical variations in wind farm complaints from Australians.

1. Nearly 65% of Australian wind farms, 53% of which have turbines >1 MW, have never been subject to noise or health complaints. These farms have an estimated 21,633 residents within 5 km and have operated complaint-free for a cumulative 267 years. No complaints were reported in Western Australia and Tasmania.
2. One in 254 residents across Australia appeared to have ever complained about health and noise, and 73% of these residents live near 6 wind farms that have been targeted by anti-wind farm groups. Ninety percentage of complaints were made after anti-wind farm groups added health concerns to their wider opposition in 2009.
3. In the years after, health or noise complaints were rare despite large and small-turbine wind farms having operated for many years.

It was suggested that reported historical and geographical variations in complaints were consistent with "communicated diseases" with nocebo effects likely to play an important role in the etiology of complaints rather than direct effects from turbines. This novel work highlighted the role of negative expectations and how they could lead to the development of complaints near wind farms. These findings were supported by many other studies that were suggestive of subjective variables, rather than wind turbine specific variables, as the source of annoyance for some people.

Whitfield Aslund et al. (36): Whitfield Aslund et al. used previously reported dose–response relationships between wind turbine noise and annoyance to predict the level of community noise annoyance that may occur in the province of Ontario. Prediction for future wind farm developments (planned, approved, or in process) were compared to previously reported rates of annoyance that were associated with more common noise sources (e.g., road traffic). Modeled noise levels and distance to the nearest wind farm-related noise source were compiled for over 8,000 individual receptor locations (i.e., buildings, dwellings, campsites, places of worship, institutions, and/or vacant lots) from 13 wind power projects in the province of Ontario that had been approved since 2009 or were under Ministry of the Environment (MOE) review as of July 2012. This information was then compared to the wind turbine noise specific dose–response relationships for self-reported annoyance from Pedersen et al. (17) and Bakker et al. (26) using data collected from 725 survey respondents living in the proximity of wind turbines (<2.5 km) in the Netherlands.

One of the study findings was that a distinct exponentially decreasing relationship was observed between distance to the nearest noise source and the sound pressure level predicted. However, although distance to the nearest noise source could explain a large proportion (86%) of the total variance in predicted sound pressure levels, other sources of variation are also important; predicted sound pressure levels at a set distance varied by approximately 5–10 dB(A) and the distance at which a set sound pressure level was met varied by approximately 1000 m. These variations reflect differences in the noise model inputs such as the physical

design and noise emission ratings of the turbines (and transformer substations, if present) used in different projects and the total number of turbines (and transformer substations, if present) in the vicinity of the receptor location. Given that noise levels can vary substantially at a given distance, these data highlighted the inadequacy of using distance to the nearest turbine as a proxy for wind turbine noise exposure.

One of the other findings was that, for non-participating receptors, predicted rates of noise-related annoyance (when indoors) would not exceed 8%, with further reductions in the rates of annoyance at increased distances (i.e., >1 km). In comparison, it had previously been established that approximately 8% of adult Canadians reported being either "very or extremely bothered, disturbed, or annoyed" by noise in general when they were at home and 6.7% of adult Canadians indicated they were either "very or extremely annoyed" by traffic noise specifically (54). Even in small Canadian communities (i.e., <5000 residents) that are typically associated with low background noise levels, 11% of respondents were moderately to extremely annoyed by traffic noise (54). This analysis suggested that the current wind turbine noise restrictions in Ontario will limit community exposure to wind turbine related noise such that levels of annoyance are unlikely to exceed previously established background levels of noise-related annoyance from other common noise sources.

LOW-FREQUENCY NOISE AND INFRASOUND

As reviewed by Knopper and Ollson (9), a number of sources have proposed that the self-reported health effects of some people living near wind turbines may be due to LFN and infrasound [e.g., (20, 39, 55)]. However, infrasound and LFN are not unique to wind turbines; natural sources of infrasound include meteors, volcanic eruptions, ocean waves, wind, and any effect that leads to slow oscillations of the air (11). Measured LFN and infrasound levels from wind turbines have been shown to comply with available standards and criteria published by numerous government agencies including the UK Department for Environment, Food, and Rural Affairs; the American National Standards Institute; and the Japan Ministry of Environment (22). Therefore, Knopper and Ollson (9) concluded that the hypothesis that infrasound is a causative agent in health effects does not appear to be supported. With some exceptions, more recent studies (summarized below) generally support this hypothesis.

Møller and Pedersen (37): Møller and Pedersen conducted a LFN study from four large turbines (>2 MW) and 44 other small and large turbines that were aggregated (7 > 2 and 37 < 2 MW). Low-frequency sound (LFS) insulation was measured for 10 rooms under normal living conditions in houses exposed to LFN. They concluded that the spectrum of wind turbine noise moves down in frequency with increasing turbine size. They also suggested that the low-frequency part of the noise spectrum plays an important role in the noise at neighboring properties. They hypothesized that if the noise from the investigated large turbines had an outdoor level of 44 dB(A) (the maximum of the Danish regulation for wind turbines) there was a risk that a substantial proportion of the residents would be annoyed by LFN, even indoors. However, the authors' work did not include a survey of annoyance surrounding the turbines and did not provide any data to support this hypothesis. In terms of infrasound (sound below 20 Hz), they concluded that the levels were relatively low when human sensitivity to these frequencies was accounted for. Even in close proximity to turbines, the infrasonic sound pressure level was below the normal hearing threshold. Overall, this study suggested that LFN could be an important component of the overall noise levels from wind turbines. However, it did not provide a link between modeled or measured values and potential health effects of nearby residents. Rather, it hypothesized that at 44 dB(A), at least a portion of the annoyance could be attributed to LFN levels.

Bolin et al. (38): Bolin et al. (38) conducted a literature review over a 6-month period ending April 2011 into the potential health effects related to infrasound and LFN exposure surrounding wind turbines. They conducted the search using PubMed, PsycInfo, and Science Citation Index. In addition, they conducted gray literature searches and personally contacted researchers and noise consultants working with wind turbine noise. They concluded that the dominant source of wind turbine generated LFN was from incoming turbulence interacting with the blades. They found no evidence in the literature that infrasound in the 1–20 Hz range contributed to perceived annoyance or other health effects. They also opined that LFN from modern wind turbines could be audible at typical levels in residential settings, but did not exceed levels from other common noise sources, such as road traffic noise.

The authors concluded that empirical support was lacking for claims that LFN and infrasound cause serious health affects in the form of "vibroacoustic disease (VAD)," "wind turbine syndrome," or harmful effects on the inner ear. This conclusion was similar to that provided in the Massachusetts Department of Environmental Protection (MassDEP) and Massachusetts Department of Public Health (MDPH) expert panel review released in January 2012.

Rand et al. (39) and Ambrose et al. (40): in the fall of 2011, Rand et al. published their findings on noise measurements taken around a residential home online in the Bulletin of Science, Technology and Society (BSTS) (39). In 2012, a similar article appeared in BSTS, but with Ambrose as first author. After learning about reported noise and health issues from some residents living near three wind turbines (Vestas, Model V82, 1.65 MW each) in Falmouth, MA, USA, Ambrose et al. conducted a study to investigate the role of infrasound and LFS in these complaints. What led Ambrose et al. to focus on infrasound and LFS was the home owner's complaints about discomfort and a number of symptoms (i.e., headaches, ear pressure, dizziness, nausea, apprehension, confusion, mental fatigue, inability to concentrate, and lethargy). These observations were reported to be associated with being indoors when the wind turbines were operating during moderate to strong winds. Ambrose et al. state: *"Typically, indoors the A-weighted sound level is lower than outdoors when human activity is at a minimum. This strongly suggested that the A-weighted sound level might not correlate very well [sic] the wind turbine complaints. This may be indicative of another cause such as low- or very-low-frequency energy being involved."*

The authors made acoustic measurements and viewed the data with dBL (unweighted) and dB(A), (C), and (G) filtering between April 17 and 19, 2011, at four locations [260 ft (~87 m), 830 ft (~277 m), 1,340 ft (~450 m), and 1,700 ft (~570 m)] between one turbine and one residence. The relationship between sound [dB(A), (G), and (L)] and health effects was based on measurements at 1,700 ft. Ambrose et al. reported that within

20 min, both authors had difficulties performing ordinary tasks and within 1 h both were "*debilitated and had to work much harder mentally.*" They also claimed that as time went on their symptoms became more severe.

The authors reported being affected when wind speeds were greater than 10 m/s at the hub height of the turbines and when measured sound levels were in the 18–24 dB(A) range inside [51–64 dB(G); 62–74 dB(L)] and 32–46 dB(A) outside [49–65 dB(G); 57–69 dB(L)]. They reported that they felt effects inside and outside but preferred being outside. They noted that it took a week to recover but one researcher had recurring symptoms (of nausea and vertigo) for over 7 weeks. There are a number of uncertainties in the Ambrose et al. white paper and the BSTS articles, which diminished the strength of their conclusions. This was the first written account we are aware of that suggested acute health effects from exposure to sound from wind turbines. The recent MassDEP and MDPH (56) report provided this comment regarding the Ambrose et al. study: "*Importantly, while there is an amplification at these lower frequencies, the indoor levels (unweighted) are still far lower than any levels that have ever been shown to cause a physical response (including the activation of the OHC) in humans.*"

Further, studies where biological effects observed following infrasound exposure were conducted at sound pressure levels much greater than measured by Ambrose et al. [e.g., (11); 145 and 165 dB; (57): 130 dB] and much greater than what is produced by wind turbines. There are over 100,000 wind turbines in operation globally. Indeed, the idea of overt acute debilitating effects (even lasting several weeks after removal from exposure) appears to be unique to these authors.

Turnbull et al. (41): Turnbull et al. developed an underground technique to measure infrasound and applied this process at two Australian wind farms as well as in the vicinities of a beach, a coastal cliff, the city of Adelaide, and a power station. The measured levels were compared against one another and against the infrasound audibility threshold of 85 dB(G). The authors reported that the measured level of infrasound within the wind farms was well below the audibility threshold and was similar to that of urban and coastal environments and near other engineered noise sources. Indeed, the level of infrasound from wind farms at 360 and 85 m [61 and 72 dB(G), respectively] was comparable to that observed at a distance of 25 m from ocean waves [75 dB(G)].

Crichton et al. (7): this study examined the possibility that expectations of negative health effects from exposure to infrasound promote symptom reporting. A sham controlled, double-blind provocation study was conducted in which participants were exposed to 10 min of infrasound and 10 min of sham infrasound. A total of 54 participants (34 women, 20 men) were randomized into high- or low-expectancy groups and presented with audiovisual information (including internet material) designed to invoke either high or low expectations that exposure to infrasound causes specific symptoms (e.g., headache, ear pressure, itchy skin, sinus pressure, dizziness, vibrations within the body). Notably, participants in the high-expectancy group reported significant increases in the number and intensity of symptoms experienced during exposure to both infrasound and sham infrasound. Conversely, there were no symptomatic changes in the low-expectancy group.

Based on their findings, Crichton et al. (7) concluded: "*Healthy volunteers, when given information about the expected physiological effect of infrasound, reported symptoms that aligned with that information, during exposure to both infrasound and sham infrasound. Symptom expectations were created by viewing information readily available on the Internet, indicating the potential for symptom expectations to be created outside of the laboratory, in real world settings. Results suggest psychological expectations could explain the link between wind turbine exposure and health complaints.*" These results were consistent with the findings of other researchers, who have observed increased concern about the health risks associated with exposure to certain environmental hazards can lead to elevated symptom reporting, even when no objective health risk is presented (58, 59).

Crichton et al. (8): building on their previous publication that negative expectations established by the media and internet can significantly increase health-related complaints by exposed individuals (8), the authors investigated how positive expectations can produce a reduction in symptoms. Sixty participants were exposed to audible wind farm sound [43 dB(A)] and infrasound [9 Hz, 50.4 dBL (unweighted)] previously recorded 1 km from a wind farm, in two, 7 min session. Following baseline measurements, expectations were developed by watching videos that either promoted the negative health effects or the potentially therapeutic health effects of exposure to infrasound. Expectations were found to significantly alter symptom reporting: participants who were primed with negative expectations became more symptomatic over time, suggesting that their experiences during the first exposure session reinforced expectations and led to heightened symptomatic experiences in subsequent sessions. Upwards of 77% of participants in the negative expectation group reported a worsening of symptoms. In contrast, 90% of participants in the positive expectation group reported improvements in physical symptoms after the listening session. This was the first study to show that a placebo response could be brought on by positive pre-exposure expectations and influence participants exposed to wind farm noise. The authors concluded that negative expectations created by the media could account for the increase in negative health effects reported by individuals exposed to wind farm noise. Overall, this investigation provided further evidence that physiological outcomes can be influenced by established expectations.

ELECTROMAGNETIC FIELDS

Concerns about the ever-present nature of EMF (also called electric and magnetic fields) and possible health effects have been raised by some in the global community for a number of years. However, the science around EMF and possible health concerns has been extensively researched, with tens of thousands of scientific studies published on the issue. Government and medical agencies including Health Canada (60), the World Health Organization (61), the International Commission on Non-Ionizing Radiation Protection (62), the International Agency for Research on Cancer (63), and the US National Institute of Health (NIH) and National Institute of Environmental Health Sciences (64) have all thoroughly reviewed the available information. While individual opinions on the issue vary, the weight of scientific evidence does not support a causal link between EMF and health issues at levels typically encountered by people.

Short-term exposure to EMF at high levels is known to cause nerve and muscle stimulation in the central nervous system. Based

on this information, the ICNIRP, a group recognized by the WHO as the international independent advisory body for non-ionizing radiation protection, established an acute exposure guideline of 2,000 mG for the general public, based on power frequency EMF of 50–400 Hz (62). With respect to long-term exposure to low levels of EMF, it needs to be acknowledged that the IARC and WHO have categorized EMF as a Class 2B possible human carcinogen, based on a weak association of childhood leukemia and magnetic field strength above 3–4 mG (63). This means there is limited evidence of carcinogenicity in humans and inadequate evidence of carcinogenicity in experimental animals. These human studies are weakened by various methodological problems that the WHO has identified as a combination of selection bias, some degree of confounding and chance (65). There are also no globally accepted mechanisms that would suggest that low-level exposures are involved in cancer development and animal studies have been largely negative (65). Thus, the WHO has stated that, based on approximately 25,000 articles published over the past 30 years, the evidence linking childhood leukemia to EMF exposure is not strong enough to be considered causal (61). Concerns have also been raised by some about a relationship between EMF and a range of various health concerns, including cancers in adults, depression, suicide, and reproductive dysfunction, among several others. The WHO (65) has stated: "*. . .scientific evidence supporting an association between ELF [extremely low frequency] magnetic field exposure and all of these health effects is much weaker than for childhood leukaemia.*"

Recently, worries about exposure to EMF from wind turbines, and associated electrical transmission, has been raised at public meetings and legal proceedings. These fears have not been based on any actual measurements of EMF exposure surrounding existing projects but appear to follow from concerns raised from internet sources and misunderstanding of the science. There has been limited research conducted on wind turbine emissions of EMF, either from the turbines themselves, or from the power lines required for distribution of the generated electricity. However, based on the weight of evidence it is not expected that EMF from wind turbines is likely to be a causative agent for negative health effects in the community. Only three papers were retrieved in the preparation of this review that examined this issue specifically.

Havas and Colling (42): the paper indicated that there were some people who lived around wind turbines that complained of difficulty sleeping, fatigue, depression, irritability, aggressiveness, cognitive dysfunction, chest pain/pressure, headaches, joint pain, skin irritations, nausea, dizziness, tinnitus, and stress. The authors suggested that these symptoms could be caused by electromagnetic waves in the form of poor power quality (dirty electricity) and ground current resulting in health effects in those that are electrically hypersensitive. They indicated that individuals reacted differently to both sound and electromagnetic waves and this could explain why not everyone experienced the same health effects living near turbines. Ground current or stray voltage was also purported to be a potential cause of health effects surrounding wind turbines. However, this paper was hypothetical and speculative in nature and no data were presented to support the author's opinions. Presently, there are no quantitative data in the scientific literature to support the claims made in Havas and Colling (42).

Israel et al. (43): these authors conducted EMF, sound, and vibration measurements surrounding one of the largest wind energy parks in Bulgaria, located along the Black Sea. The purpose of the study was to determine if levels of wind turbine emissions were within Bulgarian and European limits for workers and the general population. In addition, they sought to determine if their previously established 500 m setback zone around the wind park was adequate. The wind park consisted of 55 Vestas V90 3 MW towers. The measurements took place over a 72-h period when temperatures were between 0 and 5.5°C. Actual distances to the receptor locations were not reported, although it is suspected that they would be in the vicinity of 500 m from the closest turbines.

The EMF levels measured within 2–3 m of the wind turbines were between 0.133 and 0.225 mG. These values are comparable to or lower than magnetic field measurements that have been reported in the proximity of typical household electrical devices (66). It should be noted that the values observed by Israel et al. were approximately four orders of magnitude lower than the ICNIRP (62) guideline of 2,000 mG for the general public for acute exposure. Based on these findings, Israel et al. concluded that the EMF levels from wind turbines were at such low level as to be insignificant compared to values found in residential areas and homes. The findings reported by Israel et al. of actual measurements of EMF surrounding wind turbines were contrary to the hypothesis presented by Havas and Colling (42).

The noise measurements performed by Israel et al. met the requirements of Bulgarian legislation for day [55 dB(A)], evening [50 dB(A)], and night [45 dB(A)] and it was concluded that the wind turbines contributed only 1–3 dB(A) above existing background levels. Vibration measurements surrounding the turbines had values close to zero, which indicated that this was not a contributing emission factor of exposure for people living around wind turbines. Overall, the authors concluded: "*. . .the studied wind power park complies with the requirements of the national and European legislation for human protection from physical factors–electric and magnetic fields up to 1 kHz, noise, vibration, and do not create risk for both workers in the area of the park and the general population living in the nearest villages.*"

McCallum et al. (44): this study was carried out at the Kingsbridge 1 Wind Farm located near Goderich, ON, Canada. Magnetic field measurements (milligauss) were collected in the proximity of 15 Vestas 1.8 MW wind turbines, two substations, various buried and overhead collector and transmission lines, and nearby homes. Data were collected during three operational scenarios to characterize potential EMF exposure: "high wind" (generating power), "low wind" (drawing power from the grid, but not generating power), and "shut off" (neither drawing, nor generating power).

Background levels of EMF (0.2–0.3 mG) were established by measuring magnetic fields around the wind turbines under the "shut off" scenario. Magnetic field levels detected at the base of the turbines under both the "high wind" and "low wind" conditions were low (mean = 0.9 mG; $n = 11$) and rapidly diminished with distance, becoming indistinguishable from background within 2 m of the base. Magnetic fields measured 1 m above buried collector lines were also within background ($\leq$0.3 mG). Beneath overhead 27.5 and 500 kV transmission lines, magnetic field levels of up to 16.5 and 46 mG, respectively, were recorded. These levels also

diminished rapidly with distance. None of these sources appeared to influence magnetic field levels at nearby homes located as close as just over 500 m from turbines, where measurements immediately outside of the homes were $\leq$0.4 mG. The results suggested that there was nothing unique to wind farms with respect to EMF exposure; in fact, magnetic field levels in the vicinity of wind turbines were lower than those produced by many common household electrical devices (e.g., refrigerator, dishwasher, microwave, hairdryer) and were well below any existing regulatory guidelines with respect to human health.

SHADOW FLICKER

The main health concern associated with shadow flicker is the risk of seizures in those people with photosensitive epilepsy. As reviewed by Knopper and Ollson (9), Harding et al. (14) and Smedley et al. (19) have published the seminal studies dealing with this concern. Both authors investigated the relationship between photo-induced seizures (i.e., photosensitive epilepsy) and wind turbine blade flicker (also known as shadow flicker). Both studies suggested that flicker from turbines that interrupt or reflect sunlight at frequencies >3 Hz pose a potential risk of inducing photosensitive seizures in 1.7 people per 100,000 of the photosensitive population. For turbines with three blades, this translates to a maximum speed of rotation of 60 rpm. Modern turbines commonly spin at rates well below this threshold. For example, the following spin rates for four different models of wind turbines have been obtained from the turbine specification sheets:

- Siemens SWT-2.3: 6–16 rpm
- REpower MM92: 7.8–15.0 rpm
- GE 1.6–100: 9.75–16.2 rpm
- Vestas V112-3.0: 6.2–17.1 rpm

In 2011, the Department of Energy and Climate Change (67) released a consultant's report entitled "Update of UK Shadow Flicker Evidence Base." The report concluded that: *"On health effects and nuisance of the shadow flicker effect, it is considered that the frequency of the flickering caused by the wind turbine rotation is such that it should not cause a significant risk to health."* Furthermore, the expert panel convened by MassDEP and MDPH (56) concluded that the scientific evidence suggests that shadow flicker does not pose a risk of inducing seizures in people with photosensitive epilepsy.

Germany is one of the only countries to implement formal shadow flicker guidelines, which are part of the *Federal Emission Control Act* (68). These guidelines allow:

- maximum 30 h per year of astronomical maximum shadow (worst case);
- maximum 30 min worst day of astronomical maximum shadow (worst case); and
- maximum 8 h per year actual.

Although shadow flicker from wind turbines is unlikely to lead to a risk of photo-induced epilepsy, there has been little if any research conducted on how it could heighten the annoyance factor of those living in proximity to turbines. It may however be included in the notion of visual cues.

REVIEW ARTICLES, EDITORIALS, AND SOCIAL COMMENTARIES

In addition to the articles reviewed above that reported the results of surveys and experiments designed to specifically investigate potential environmental stressors that have been associated with wind turbines (i.e., overall noise, LFN and infrasound, EMF, and shadow flicker), a number of published and peer-reviewed articles were identified that present reviews of the available data, opinion pieces, and/or social commentaries. These articles are reviewed in detail below.

Bulletin of Science, Technology and Society: Special Edition 2011, 31(4): in August 2011, authors of a number of popular literature studies published their findings as a series of nine articles in a special edition of the Bulletin of Science, Technology and Society (BSTS) devoted entirely to wind farms and potential health effects[1]. Many of the articles in the special edition were written as opinion pieces or social commentaries and did not provide detailed methodologies used to test hypotheses as is expected in the publication of scientific research articles. Based on a critical review of each of the articles (69), it is our opinion that the series suffers numerous flaws from a scientific, technological, and social basis. Many of the claims used as evidence of a relationship between health effects and wind turbines were unsubstantiated [e.g., Phillips (70) is entirely unsupported and contains alarmist extrapolations], without proper references [e.g., (70, 71)] and based on anecdotal or unconfirmed reports [e.g., (55, 70, 72, 73)], fallacious comparisons [e.g., (74)], and reaching arguments lacking a logical process [e.g., (70, 73, 75, 76)]. Further, much information given as fact was contrary to that published in the scientific literature; indeed, many authors appeared to selectively reference articles and information in a way that would benefit their own arguments [e.g., (55, 71)]. The results of this BSTS special issue failed to provide valid, defensible scientific and social arguments to suggest that wind turbines, regardless of siting considerations, cause harm to human health.

Hanning and Evans (45) and Chapman (46): in 2012, Hanning and Evans had an editorial published in the British Medical Journal (BMJ), the purpose of which was to opine on the relationship between wind turbines noise and health effects. By citing a short list of articles (12), half of which are from the non-indexed journal BSTS or from conference proceedings (3 and 3, respectively, out of 12), Hanning and Evans suggested that: *"A large body of evidence now exists to suggest that wind turbines disturb sleep and impair health at distances and external noise levels that are permitted in most jurisdictions."* and *"Robust independent research into the health effects of existing wind farms is long overdue, as is an independent review of existing evidence and guidance on acceptable noise levels."*

Shortly after publication, this editorial was rebuffed by Chapman (46), in another editorial placed in the BMJ. Chapman pointed out that there are a number of independent reviews of the literature around wind turbines and human health (Chapman points to 17 such papers not referenced by Hanning and Evans). Chapman opined that: "*These reviews strongly state that the evidence that wind turbines themselves cause problems is poor.*

[1] http://bst.sagepub.com/

They conclude that: Small minorities of exposed people claim to be adversely affected by turbines; Negative attitudes to turbines are more predictive of reported adverse health effects and annoyance than are objective measures of exposure; Deriving income from hosting wind turbines may have a "protective effect" against annoyance and health symptoms." Further debate about the original editorial is available online to view (and comment on) through the BMJ web site[2].

Farboud et al. (47): this review article looked at the effects of LFN and infrasound and questioned the existence of "wind turbine syndrome." The authors conducted a literature search for articles published within the last 10 years, using the PubMed database and the Google Scholar search engine. Their search terms included "wind turbine," "infrasound," or "LFN" and search results were limited to the English language, human trials, and either randomized control trials, meta-analyses, editorial letters, clinical trials, case reports, comments, or journal articles. A number of articles dealing with "wind turbine," "infrasound," or "LFN," and available in PubMed and Google Scholar, appear to have been missed by Farboud et al. [e.g., (9, 22, 38)]. The review included discussions on topics such as wind turbine noise measurements and regulations, wind turbine syndrome, and the effects of LFN and infrasound.

The authors discussed the use of A-weighting in noise measurements from wind turbines stating: "*The A-filter de-emphasizes all auditory energy with frequencies of less than 500 Hz, and completely ignores all auditory energy of less than 20 Hz, in an effort to estimate the noise thought to be actually processed by the ear. Hence, much of the noise produced by a wind turbine is effectively ignored.*" The authors later described the results and implications of studies looking at the effects of infrasound in the ear, and noted that infrasound and LFN are currently not recognized as disease agents. Referencing a study by Salt and Hullar (20), the authors noted that the inner hair cells of the cochlea, which is the main hearing pathway in mammals, are not sensitive to infrasound. Conversely, the outer hair cells of the cochlea are more sensitive to LFN and infrasound and can be stimulated at levels below the auditory threshold. Nevertheless, the authors conceded that: "*. . .low-frequency noise may well influence inner ear physiology. However, whether this actually alters function or causes symptoms is unknown.*"

It should be noted that, as discussed in the "Low-Frequency Noise and Infrasound" section of this review, there were a number of studies that specifically addressed the concerns of LFN and infrasound from wind turbines that suggested that these were unlikely to be causative agents in health effects of those living near wind turbines [e.g., (7, 11, 22, 37, 38)]. Unfortunately, none of these studies were included as part of the Farboud et al. review.

Regarding the existence of "Wind Turbine Syndrome," Farboud et al. stated that: "*There is an abundance of information available on the internet describing the possibility of wind turbine syndrome. However, the majority of this information is based on purely anecdotal evidence.*" The authors briefly discussed the various symptoms that have been self-reported by individuals and attributed to noise from wind turbines. They also pointed out that "Wind Turbine Syndrome" was not a clinically recognized diagnosis, remained unproven, and was not generally accepted within the scientific and medical community. They also mentioned that some researchers maintained that the effects of "Wind Turbine Syndrome" were just examples of the well-known stress effects of exposure to noise, as displayed by a small proportion of the population.

Farboud et al. concluded their review by suggesting that the evidence available was incomplete and until the physiological effects of LFN and infrasound were fully understood, it was not possible to conclusively state that wind turbines were not causing any of the reported effects. However, it was not clear how this conclusion might have been altered had they considered the additional available information regarding LFN and infrasound from wind turbines described elsewhere in this review [i.e., (7, 11, 22, 37, 38)].

McCubbin and Sovacool (48): McCubbin and Sovacool (48) presented a comparison of the health and environmental benefits of wind power in contrast to natural gas. The authors selected two locations: the 580 MW wind farm at Altamont Pass in California and the 22 MW wind farm in Sawtooth, ID, USA. The paper considered the environmental and economic benefits associated with each wind farm. Human health benefits were calculated based on a reduction in ambient $PM_{2.5}$ levels using well-established health impact and valuation functions from the US EPA. Additionally, benefits to the health and well-being of wildlife and avian species were quantified.

With regard to the human health impacts, the potential cost savings were associated with effects such as premature mortality, hospital admissions, emergency rooms visits, asthma attacks, and respiratory symptoms. The details of the quantification methods and equations used to calculate the benefits to externalities such as human health, wildlife, and the natural environment were not provided herein but are available in the published manuscript.

McCubbin and Sovacool determined that from 2012 to 2031 the wind turbines at Altamont Pass will avoid anywhere from $560 million to $4.38 billion in human health and climate-related externalities, and the Sawtooth wind farm will avoid from $18 million to $24 million. The authors noted that there were uncertainties associated with their quantification methods and final cost estimates; however, they claimed that the values were likely underestimated based on numerous factors that were not considered (e.g., other pollutants). They concluded that: "*Despite the uncertainties, the evidence gathered here strongly suggests that natural gas had substantial external costs that should be included in an evaluation comparing wind energy to combined cycle natural gas-fired power plants. The overall costs of electricity generated by natural gas are greater than those from wind energy when environmental and human health externalities are quantified. It remains likely that over time the relative difference will widen, making the use of wind energy even more favorable.*"

Roberts and Roberts (49): the authors conducted a summary of the peer-reviewed literature on the research that examined the relationship between human health effects and exposure to LFS and sound generated from the operation of wind turbines. The PubMed database (maintained by the US National Library of Medicine) was relied upon for retrieving the peer-reviewed literature used in this review. A number of search terms were used including: "infrasound and health effects"; "LFN and health effects"; "LFS and health effects"; "wind power and noise"; and "wind turbines AND

[2]http://www.bmj.com/content/344/bmj.e1527?tab=responses

noise." In total, 156 articles were identified with 28 articles addressing health effects and LFS related to wind turbines. Based on the collective results of the studies reviewed, Roberts and Roberts (49) found that: *"At present, a specific health condition or collection of symptoms has not been documented in the peer-reviewed, published literature that has been classified as a 'disease' caused by exposure to sound levels and frequencies generated by the operations of wind turbines. It can be theorized that reported health effects are a manifestation of the annoyance that individuals experience as a result of the presence of wind turbines in their communities."*

Chapman and St. George (50): in 2007, Alves-Pereira and Castelo Branco issued a press-release suggesting that their research demonstrated that living in proximity to wind turbines had led to the development of VAD in nearby home-dwellers (9). Alves-Pereira and Castelo Branco appear to be the primary researchers who have circulated VAD as a hypothesis for adverse health effects and wind turbines and to our knowledge this work has never appeared in a peer-reviewed article. In this paper, Chapman and St. George investigated the extent to which VAD and its alleged association with wind turbine exposure had received scientific attention, the quality of that association, and how the alleged association gained support by wind farms opponent.

Based on a structured scientific database and Google search strategy, the authors showed that *"VAD has received virtually no scientific recognition beyond the group who coined and promoted the concept. There is no evidence of even rudimentary quality that vibroacoustic disease is associated with or caused by wind turbines."* They went on to state that an implication of this "factoid" – defined as questionable or spurious statements – may have been contributing to nocebo effects among those living near turbines. That is the spread of negative, often emotive information would be followed by increases in complaints and that without such suggestions being spread, complaints would be less. These results highlighted the role that perception plays in the human health wind turbine debate and underscored the role of proper risk communication in communities.

Jeffery et al. (51, 52): the overall goal of these commentary pieces was to provide information to physicians regarding the possible health effects of exposure to noise produced by wind turbines and how these may manifest in patients. In the 2013 article, information about the *Green Energy Act* was presented in such a way that implied that the overall goal of the Act was to remove protective noise regulations and allow wind turbines to be placed "in close proximity to family homes." The authors suggested that there has been a concerted effort to minimize the potential health risks while convincing the general public and physicians that wind turbines are beneficial. No evidence was given to support these claims. Case reports and publications that reported adverse effects following wind turbines noise exposure were briefly discussed; however, only the negative health effects were highlighted. Older literature and a number of non-peer-reviewed articles and media reports were used to support the author's opinions. The 2014 paper is very similar to that published in 2013. The authors provided a very one-sided opinion in their review of the issue of wind turbines and adverse health effects. They have missed a number of key and pertinent articles that have been published on the issue. Overall the authors did not provide adequate data or support for their arguments, in both papers, nor did they provide accurate information regarding the weight of scientific data on the issue.

WEIGHT OF EVIDENCE CONCLUSIONS

There are roughly 60 studies that have been conducted worldwide on the issue of wind turbines and human health. In terms of effects being related to wind turbine operational effects and wind turbine noise, there are fewer than 20 articles. The vast majority has been published in one journal (BSTS) and many of these authors sit on advisory board of the Society for Wind Vigilance, an advocacy group in the province of Ontario. However, with respect to effects being more likely attributable to a number of subjective variables (when turbines are sited correctly), there are closer to 45 articles. These articles are published by a variety of different authors with wide and diverse affiliations. Indeed, conclusions stemming from these articles are supported by studies where audible and inaudible noise has been quantified from operational wind turbines.

Based on the findings and scientific merit of the research conducted to date, it is our opinion that the weight of evidence suggests that when sited properly, wind turbines are not related to adverse health effects. This claim is supported (and made) by findings from a number of government health and medical agencies and legal decisions [e.g., (56, 77–80)]. Collectively, the evidence has shown that while noise from wind turbines is not loud enough to cause hearing impairment and is not causally related to adverse effects, wind turbine noise can be a source of annoyance for some people and that annoyance may be associated with certain reported health effects (e.g., sleep disturbance), especially at sound pressure levels >40 dB(A).

The reported correlation between wind turbine noise and annoyance is not unexpected as noise-related annoyance [described by Berglund and Lindvall (81) as a *"feeling of displeasure evoked by a noise"*] has been extensively linked to a variety of common noise sources such as rail, road, and air traffic (81–83). Noise-related annoyance from these more common sources is prevalent in many communities. For instance, results of national surveys in Canada and the U.K. by Michaud et al. (54) and Grimwood et al. (84), respectively, suggested that annoyance from noise (predominantly traffic noise) may impact approximately 8% of the general population. Even in small communities in Canada (i.e., <5000 residents) where traffic is relatively light compared to urban centers, Michaud et al. (54) reported that 11% of respondents were moderately to extremely annoyed by traffic noise.

Although annoyance is considered to be the least severe potential impact of community noise exposure (83, 85), it has been hypothesized that sufficiently high levels of annoyance could lead to negative emotional responses (e.g., anger, disappointment, depression, or anxiety) and psychosocial symptoms (e.g., tiredness, stomach discomfort, and stress) (83, 86–90). However, it is important to note that noise annoyance is known to be strongly affected by attitudinal factors such as fear of harm connected with the source and personal evaluation of the source (91–93) as well as expectations of residents (92). For wind turbines, this has been reflected in studies that have shown that subjective variables like evaluations of visual impact (e.g., beautiful vs. ugly), attitude to wind turbines (benign vs. intruders), and personality traits are more strongly related to annoyance and health effects than noise

itself [e.g., (4, 5, 16, 17, 31)]. Thus, it is likely that the adverse effects exhibited by some people who live near wind turbines are a response to stress and annoyance, which are driven by multiple environmental and personal factors, and are not specifically caused by any unique characteristic of wind turbines. This hypothesis is also supported by the observation that people who economically benefit from wind turbines have significantly decreased levels of annoyance compared to individuals that received no economic benefit, despite exposure to similar, if not higher, sound levels (17).

There is also a growing body of research that suggests that nocebo effects may play a role in a number of self-reported health impacts related to the presence of wind turbines. Negative attitudes and worries of individuals about perceived environmental risks have been shown to be associated with adverse health-related symptoms such as headache, nausea, dizziness, agitation, and depression, even in the absence of an identifiable cause (94–96). Psychogenic factors, such as the circulation of negative information and priming of expectations have been shown to impact self-assessments following exposure to wind turbine noise (6–8). It is therefore important to consider the role of mass media in influencing public attitudes about wind turbines and how this may alter responses and perceived health impacts of wind turbines in the community. For example, Deignan et al. (97) recently demonstrated that newspaper coverage of the potential health effects of wind turbines in Ontario has tended to emphasize "fright factors" about wind turbines. Specifically, Deignan et al. (97) reported that 94% of articles provided "*negative, loaded or fear-evoking*" descriptions of "*health-related signs, symptoms or adverse effects of wind turbine exposure*" and 58% of articles suggested that the effects of wind turbines on human health were "*poorly understood by science.*" It is possible that this type of coverage may have a significant impact on attitudinal factors, such as fear of the noise source, that are known to increase noise annoyance (91–93).

Stress/annoyance is not unique to living in proximity to wind turbines. The American Psychological Association (98) published a report stating that the majority of Americans are living with moderate (4 to 7 on a scale of 1 to 10) or high (8 to 10 on a scale of 1 to 10) levels of stress. APA identified money, work, and the economy as the most often cited sources of stress in Americans followed by family responsibilities, relationships, job stability, housing costs, health concerns, health problems, and safety. Stress from these and other sources can lead to a number of adverse health effects that are commonplace in society. The Mayo Clinic (99) identifies irritability, anger, anxiety, sadness/guilt, change in sleep, fatigue, difficulty concentrating or making decisions, loss of interest/enjoyment, nausea, headache, and tinnitus as common symptoms of stress. Interestingly, these symptoms are nearly identical to those suggested by McMurtry (55) as criteria for a *"diagnosis of adverse health effects in the environs of industrial wind turbines."*

Based on the available evidence, we suggest the following best practices for wind turbine development in the context of human health. However, it should be noted that subjective variables (e.g., attitudes and expectations) are strongly linked to annoyance and have the potential to facilitate other health complaints via the nocebo effect. Therefore, it is possible that a segment of the population may remain annoyed (or report other health impacts) even when noise limits are enforced.

1. Setbacks should be sound-based rather than distance-based alone.
2. Preference should be given to sound emissions of $\leq$40 dB(A) for non-participating receptors, measured outside, at a dwelling, and not including ambient noise. This value is the same as the WHO (Europe) night noise guideline (100) and has been demonstrated to result in levels of wind turbine community annoyance similar to, or lower than, known background levels of noise-related annoyance from other common noise sources.
3. Post construction monitoring should be common place to ensure modeled sound levels are within required noise limits.
4. If sound emissions from wind projects is in the 40–45 dB(A) range for non-participating receptors, we suggest community consultation and community support.
5. Setbacks that permit sound levels >45 dB(A) (wind turbine noise only; not including ambient noise) for non-participating receptors directly outside a dwelling are not supported due to possible direct effects from audibility and possible levels of annoyance above background.
6. When ambient noise is taken into account, wind turbine noise can be >45 dB(A), but a combined wind turbine-ambient noise should not exceed >55 dB(A) for non-participating and participating receptors. Our suggested upper limit is based on WHO (100) conclusions that noise above 55 dB(A) is "*considered increasingly dangerous for public health,*" is when "*adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed*" and "*cardiovascular effects become the major public health concern, which are likely to be less dependent on the nature of the noise.*"

Over the past 20 years, there has been substantial proliferation in the use of wind power, with a global increase of over 50-fold from 1996 to 2013 (1). Such an increase of investment in renewable energy is a critical step in reducing human dependency on fossil fuel resources. Wind-based energy represents a clean resource that does not produce any known chemical emissions or harmful wastes. As highlighted in a recent editorial in the British Medical Journal, reducing air pollution can provide significant health benefits, including reducing asthma, chronic obstructive pulmonary disease, cancer, and heart disease, which in turn could provide significant savings for health care systems (101). By following our proposed health-based best practices for wind turbine siting, wind energy developers, the media, members of the public and government agencies can work together to ensure that the full potential of this renewable energy source is met.

AUTHOR CONTRIBUTIONS

All authors contributed in varying degrees to writing, editing, and reviewing this manuscript.

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Evidence on Wind Farms and Human Health

February 2015

WORKING TO BUILD A HEALTHY AUSTRALIA

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Summary of the evidence

Introduction

- This Information Paper provides a summary of evidence from research on wind farms and human health, based on the findings of comprehensive independent reviews commissioned by the National Health and Medical Research Council (NHMRC).
- Internationally, there is little research evidence regarding the health effects of wind farms. Over 4,000 papers were identified in the reviews and, of these papers, only 13 studies were found that considered possible relationships between wind farm emissions and health outcomes (direct evidence). Only one of these studies was conducted in Australia.
- Following comprehensive assessment of the evidence obtained from the independent reviews and additional information provided by expert review and public consultation, the body of direct evidence was found to be small and of poor quality.
- Supporting evidence was also reviewed to gain greater understanding of the characteristics of wind farm emissions (background evidence), their likely effects on the human body (mechanistic evidence) and whether any health effects have been observed from other sources producing similar emissions (parallel evidence).

Statement on the evidence

- Examining whether wind farm emissions may affect human health is complex, as both the character of the emissions and individual perceptions of them are highly variable.
- After careful consideration and deliberation, NHMRC concluded that there is currently no consistent evidence that wind farms cause adverse health effects in humans. This finding reflects the results and limitations of the direct evidence and also takes into account parallel evidence on the health effects of similar emissions from other sources.
- Given the poor quality of current evidence and the concern expressed by some members of the community, there is a need for high quality research into possible health effects of wind farms, particularly within 1,500 metres (m).

Noise

- *Physical and mental health* — There is no direct evidence that exposure to wind farm noise affects physical or mental health. While exposure to environmental noise is associated with health effects, these effects occur at much higher levels of noise than are likely to be perceived by people living in close proximity to wind farms in Australia. The parallel evidence assessed suggests that there are unlikely to be any significant effects on physical or mental health at distances greater than 1,500 m from wind farms.
- *Annoyance* — There is consistent but poor quality direct evidence that wind farm noise is associated with annoyance. Bias of different kinds and confounding factors are possible explanations for the associations observed. While the parallel evidence suggests that prolonged noise-related annoyance may result in stress, which may be a risk factor for cardiovascular disease, annoyance was not consistently defined in the studies and a range of other factors may have contributed to its reported association with wind farm noise.

- *Sleep disturbance* — There is less consistent poor quality direct evidence of an association between sleep disturbance and wind farm noise. However, sleep disturbance was not objectively measured in the studies and bias of different kinds and confounding factors are possible explanations for the associations observed. While chronic sleep disturbance is known to affect health, the parallel evidence suggests that wind farm noise is unlikely to disturb sleep at distances of more than 1,500 m from wind farms.
- *Quality of life* — There is also less consistent poor quality direct evidence of an association between wind farm noise and poorer quality of life. Measurement of quality of life is generally subjective and the studies did not explore whether the reported associations could be explained by bias of different kinds or confounding factors.
- *Infrasound and low-frequency noise* — There is no direct evidence that considered possible effects on health of infrasound or low-frequency noise from wind farms. Exposure to infrasound and low-frequency noise in a laboratory setting has few, if any, effects on body functions. However, this exposure has generally been at much higher levels than occurs in the vicinity of wind farms, has been of short duration and has not replicated all of the characteristics of wind farm noise.
- *Perception of wind farm noise* — Background evidence indicates that wind farm noise is generally in the range of 30–45 A-weighted decibels (dBA) at a distance of 500–1,500 m from a wind farm and below 30–35 dBA beyond 1,500 m. Although individuals may perceive aspects of wind farm noise at greater distances, it is unlikely that it will be disturbing at distances of more than 1,500 m. Noise from wind farms, including its content of low-frequency noise and infrasound, is similar to noise from many other natural and human-made sources. However, there are some unique characteristics of wind farm noise, such as the "whoosh" or "thump" sometimes heard, which might influence the way in which it is perceived.

Shadow flicker

- There is insufficient direct evidence to draw any conclusions on an association between shadow flicker produced by wind farms and health effects.
- Flashing lights can trigger seizures among people with a rare form of epilepsy called photosensitive epilepsy. From the parallel evidence, the risk of shadow flicker from wind farms triggering a seizure among people with this condition is estimated to be extremely low.

Electromagnetic radiation

- There is no direct evidence from which to draw any conclusions on an association between electromagnetic radiation produced by wind farms and health effects.
- Extremely low-frequency electromagnetic radiation is the only potentially important electromagnetic emission from wind farms that might be relevant to health.
- Limited evidence suggests that the level of extremely low-frequency electromagnetic radiation close to wind farms is less than average levels measured inside and outside suburban homes.
- There is no consistent evidence of human health effects from exposure to other sources of extremely low-frequency electromagnetic radiation at much higher levels than are present near wind farms.

Introduction

Purpose of this document

This Information Paper provides Australians with a summary of the evidence on possible health effects of wind farms in humans and explains how NHMRC developed its summary based on the findings of independent reviews of the evidence.[1,2] It is intended for use by any person or group interested in wind farms.

Wind farms in Australia

Wind turbines use rotating blades attached to towers to convert wind energy into electricity. A group of wind turbines is known as a wind farm and may be located on land or offshore. Wind turbine design has evolved over the last 20 years to enable better harnessing of wind energy.[3]

Wind farms have been promoted as a viable and sustainable alternative to traditional, non-renewable forms of energy production. Since the introduction of the *Renewable Energy Act 2000*, the number of wind farms in Australia has grown substantially. At the end of 2013, there were 68 wind farms across the country and more were being constructed or planned.[4]

Why NHMRC is conducting this work

NHMRC is responsible for ensuring that Australians receive the best available, evidence-based advice on matters relating to improving health and to preventing, diagnosing and treating disease. Concern about the effects on health from living near a wind farm has been expressed by some members of the community. Therefore, NHMRC examined the evidence on health effects associated with exposure to specific emissions from wind farms — noise, shadow flicker and electromagnetic radiation.

The current investigation of the potential health effects of wind farms builds upon NHMRC's previous work in this area. In 2010, NHMRC's *Public statement: Wind turbines and health*[5] was published, with supporting evidence from *Wind turbines and health: A rapid review of the evidence*.[6] The 2010 NHMRC Public Statement concluded that there "is currently no published scientific evidence to positively link wind turbines with adverse health effects".[5] Due to the limited amount of published scientific literature, NHMRC committed to carrying out a more extensive search for evidence.

This Information Paper provides an update to NHMRC's previous work in this area. It is based on a comprehensive review of the available scientific evidence following well-established systematic review principles, which provide the most rigorous process for identifying and critically appraising evidence.

In Australia, responsibility for regulating the planning, development and operation of wind farms lies with state, territory and local governments. The outcomes of NHMRC's review may assist these organisations to make decisions about the regulation of wind farms.

NHMRC's review of the evidence will enable well-designed and targeted research to be undertaken in areas that have been identified as gaps in the evidence base (see Chapter 7, page 25).

1. Overview of the process

The development of this Information Paper involved various comprehensive evidence review and quality assurance processes to ensure that the evidence from research on wind farms and human health was appropriately identified, assessed and translated into an evidence-based summary for the Australian community. These processes are outlined below and summarised in Figure 1 (see page 6).

1.1 Independent review

In examining the possible health effects of wind farms in humans, NHMRC commissioned Adelaide Health Technology Assessment to conduct an independent review of the scientific evidence. To ensure that the independent review process was robust and transparent, internationally recognised methods were used to direct the identification, assessment and collation of the evidence.

As this is an emerging area of evidence, the independent review involved:

- a systematic review of scientific research that investigated whether health effects were directly related to distance from or exposure to any emissions from wind farms (direct evidence); and
- a broader review of supporting literature to establish:
  - the likely level of exposure to emissions produced by wind farms at nearby residences (background evidence);
  - whether it is plausible that noise, shadow flicker and electromagnetic radiation (of the type and at the levels produced by wind farms) might affect healthy functioning of the human body (mechanistic evidence); and
  - whether any health effects have been observed from these emissions when they are produced by sources other than wind farms (parallel evidence).

To ensure that this Information Paper was informed by all relevant literature, an independent review was conducted to identify peer-reviewed direct evidence published after the cut-off date for the first review. The second review also included evidence provided through public consultation and expert review of the draft Information Paper (see Section 1.4, page 5). This independent review of additional evidence was conducted by a collaborative team from the Australasian Cochrane Centre and the Monash Centre for Occupational and Environmental Health at Monash University.

1.2 Oversight by the Reference Group

The review of evidence and development of the Information Paper was guided by the Wind Farms and Human Health Reference Group (Reference Group). The Reference Group had expertise in public and environmental health, research methodology, acoustics, psychology and sleep and included a consumer advocate. Information on the membership and terms of reference of the Reference Group is included at Appendix A (see page 28).

The Reference Group:

- assisted the reviewers to develop research questions;
- reviewed and commented on drafts of the reports of the independent reviews;
- provided scientific advice on the interpretation of the evidence;
- reviewed and interpreted the parallel evidence;
- guided the development of the Information Paper;
- considered expert reviews of the draft Information Paper and submissions received through public consultation (see Section 1.4); and
- identified gaps in the evidence base to make recommendations for further research (see Chapter 7, page 25).

NHMRC appointed two observers to attend Reference Group meetings and teleconferences to observe the process. The observers' contributions to Reference Group meetings were limited to offering factual information or providing it at the request of Reference Group members at the discretion of the Chair. The observers did not engage in the scientific discussions or decision-making processes of the Reference Group.

1.3 Quality assurance processes

Rigorous quality assurance processes support the development of all NHMRC health advice, including identifying any conflicts of interest of Reference Group members, involving observers, independent methodological review, public consultation and expert review.

More detail on the processes used to ensure the quality of the review of evidence and development of the Information Paper is included in Appendix B (see page 30).

1.4 Public consultation and expert review

To ensure that all relevant evidence was identified and considered, a draft Information Paper was released for public consultation in February 2014 and submission of evidence invited. To ensure that the evidence had been accurately represented in the Information Paper, six Australian and international expert reviewers were also invited to provide comments on the draft document. The feedback from public consultation and expert review informed the further development of the draft Information Paper.

Many of the 36 public consultation submissions received detailed individual experiences of living near a wind farm and expressed concern about the possible health effects and other social impacts of wind farm developments on the surrounding community, including conflict among neighbours. While the Reference Group considered that the broader social impact of wind farms was beyond the scope of the review, it acknowledged the high level of concern that some members of the community expressed and noted the importance of considering the best available evidence to provide Australians with reliable advice on this issue.

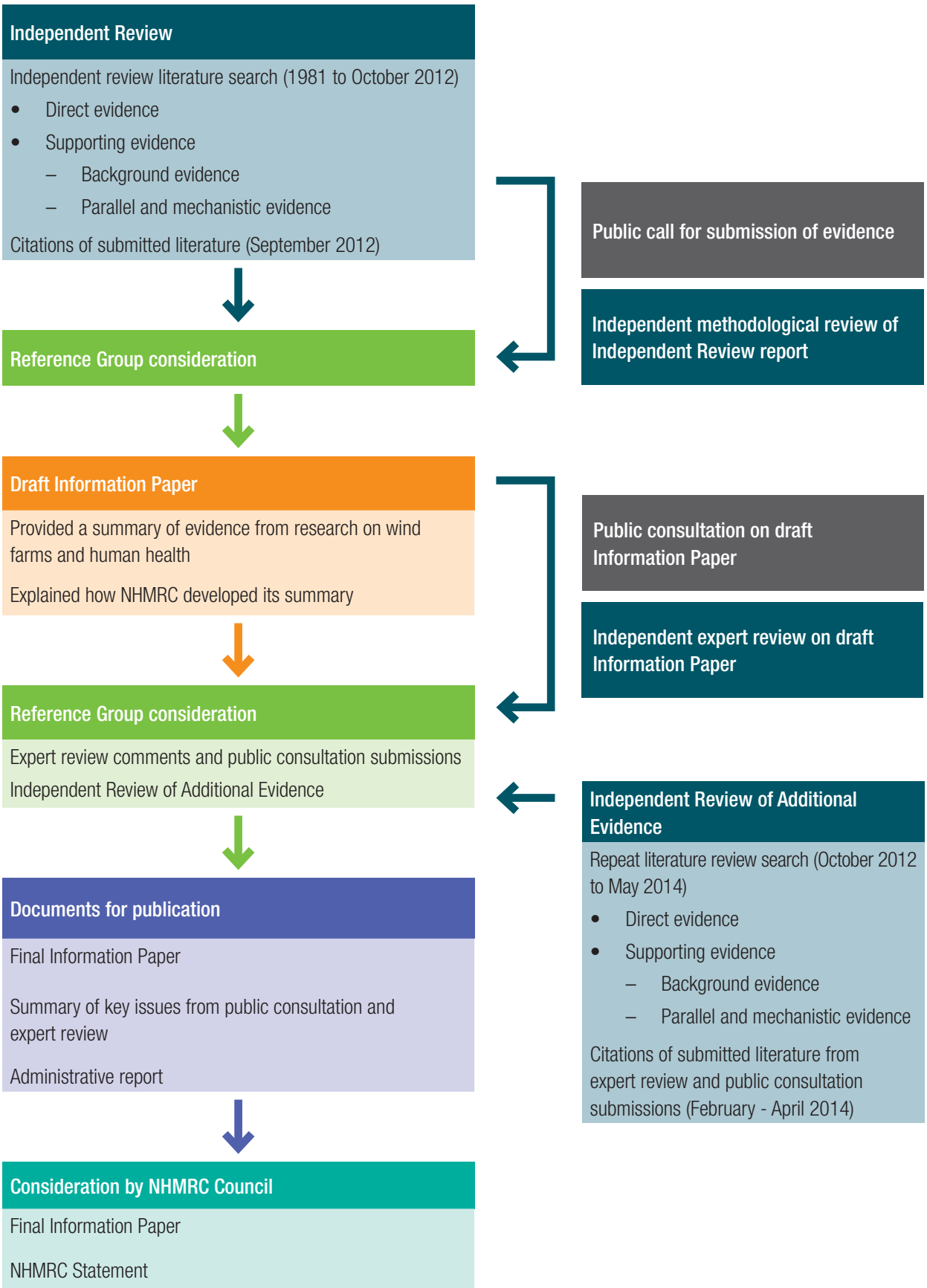


Figure 1: Overview of the comprehensive evidence review and quality assurance processes in the development of the NHMRC Information Paper: Evidence on Wind Farms and Human Health

2. Examination of the direct evidence

2.1 Identification of the direct evidence

The independent reviews searched for all of the scientific evidence on possible health effects specifically related to exposure to any emissions from wind farms. This is referred to as the *direct* evidence.

The reviewers undertook a comprehensive search of the literature in accordance with a pre-approved review protocol and search strategy for the independent reviews. While noise, shadow flicker and electromagnetic radiation were considered to be the likely emissions of interest from wind farms, the search strategy was kept broad to make sure that relevant evidence was captured. The potential effects on human health from wind farm manufacturing and monitoring (such as occupational health and safety issues), health effects due to ice throw under certain weather conditions and accidents due to mechanical failure were all considered beyond the scope of this review.

Literature for possible inclusion in the direct evidence component of the review was identified by:

- searching publication databases for peer-reviewed health literature;
- searching for relevant non peer-reviewed literature (commonly referred to as grey literature) in Google Scholar, databases of conference proceedings, selected government and scientific association websites and other grey literature sources; and
- checking the reference lists of relevant reviews and reports.

NHMRC also called for public submissions of relevant literature for inclusion in the independent review in September 2012 to help ensure that new and emerging direct evidence was considered.

The first independent review encompassed evidence published between 1981 and October 2012 and identified 2,848 references. In addition, references to 506 publicly available documents were received by NHMRC during the call for public submissions and considered in the independent review.

The independent review of additional evidence, which covered peer-reviewed literature published between October 2012 and May 2014, identified 1,912 references. During public consultation in February 2014, NHMRC again called for submissions of evidence and the 249 references received were considered in the independent review of additional evidence.

2.2 Selection of the direct evidence

For information to be considered as direct evidence it had to:

- be publicly available;
- look at exposure to wind farm emissions;
- *not* choose *only* participants who had reported health effects they attributed to wind farm emissions;
- compare two or more groups with different levels of exposure to wind farms (e.g. a “near” group and a “far” group);

- explain how the data were collected;
- assess health outcomes in the groups studied; and
- analyse the results.

While the Reference Group's Terms of Reference specified that new peer-reviewed literature be identified, the Reference Group considered it appropriate to also include non-peer-reviewed direct and background evidence in the review. This is an emerging area of research and it was deemed important to capture and consider all relevant evidence.

Personal stories, opinions and medical records submitted by individuals were not considered in the independent reviews. While individual experiences can raise the possibility of health effects from wind farms, only systematic research provides the necessary evidence to determine whether reported health effects result from exposure to wind farms.

Animal studies were also excluded, as the focus of the reviews was possible health effects in humans. The emissions investigated through animal studies differ from wind farm emissions in level and duration and the applicability of these studies to human health is uncertain. However, it is recognised that animal studies might suggest mechanisms to explain how human health effects could be caused by wind farm emissions.

In the first review, titles and abstracts of all 2,848 identified papers and the additional 506 submitted references were reviewed for relevance and 161 papers were then read in detail. Seven studies (described in eleven papers)[7-17] met the inclusion criteria for direct evidence listed above.

In the independent review of additional evidence, titles and abstracts of the 1,912 identified papers and the 249 references submitted through the public consultation process were reviewed for relevance and 94 papers were then read in detail. Six studies (described in seven papers)[18-24] were identified as providing direct evidence. One additional direct evidence paper contained further analysis of data from three studies included in the first independent review.[25]

Appendix C (see page 31) provides more detail on the process of selecting the studies.

2.3 Studies included as direct evidence

The studies included as direct evidence in the independent reviews examined wind farm noise, shadow flicker or other visual stimuli and changes to one or a combination of physical health, mental health, annoyance, sleep and quality of life.

- Seven studies (reported in nine papers) assessed self-reported **physical health** and estimated level of wind farm noise[7,10-13,18] or proximity to wind farms.[14,15,21]
- Five studies (reported in seven papers) assessed aspects of self-reported **mental health** (stress, irritability, psychological distress, anxiety and depression) and estimated level of wind farm noise[7,9,11,13] or proximity to a wind farm.[14,16]
- Six studies (reported in twelve papers) assessed **annoyance** and estimated level of wind farm noise[7,9-13,17,19,20,25] or proximity to a wind farm,[8,15] one of which also assessed annoyance and shadow flicker from wind farms.[8] One study[22] assessed annoyance associated with aircraft warning lights on wind turbines.
- Nine studies (reported in eleven papers) assessed self-reported **sleep quality** and estimated level of wind farm noise[7,9-11,13,19] or proximity to a wind farm.[8,14-16,21]
- Four studies (reported in five papers) assessed **quality of life** and proximity to wind farms.[14-16,23,24]

Of the included studies, only one was conducted in Australia. The remaining studies were conducted in Canada, Germany, Japan, the Netherlands, New Zealand, Poland, Sweden and the United States of America.

In all of these studies the participants **self-reported** their health outcomes — none of the outcomes was objectively measured (e.g. by using a test performed by a doctor or scientist).

No studies were identified that specifically looked at possible effects on human health of **infrasound** (sound at a frequency lower than 20 Hertz), **low-frequency noise** or **electromagnetic radiation** from wind farms.

2.4 Critical appraisal of the direct evidence

Critical appraisal is a systematic process used to identify the strengths and weaknesses of published research in order to assess the validity of the findings and their usefulness.

The most important components of critical appraisal of individual studies are an evaluation of the appropriateness of the study's design for the research question and a careful assessment of the key methodological features of this design.[26] Specific factors that should be considered when critically appraising epidemiological research on the association between environmental exposures and health effects include the way in which participants were selected, how information about their exposures and health outcomes was collected, whether the study adequately considered all plausible explanations for any association between an exposure and a health outcome, the suitability of the statistical methods used, and the interpretation of the findings.

The number of people included in a study is also important. When the number of participants is large, possible confounding effects can be more readily examined in the analysis and chance can be more confidently excluded as a cause for an observed association between an exposure and a health effect, or the lack of such an association. The authors' conflicts of interest should also be considered.

Considering all studies relevant to a particular research question, the evidence for an association between an exposure and an effect is stronger if there are multiple "well-conducted" studies that are consistent in their findings with respect to the association.

To support critical appraisal, the key features of the direct evidence studies reviewed were summarised in tables in the report of the initial independent review[1] (see Table 7, page 46 of the initial review) and the independent review of additional evidence[2] (see Table 1, page 13 of the additional review). An overview of the Reference Group's consideration of this evidence is provided below.

Study design and sample sizes

All of the studies that met the inclusion criteria for direct evidence used a cross-sectional design. Cross-sectional studies examine the relationship between an exposure (in this case wind farm emissions) and specific health outcomes in a defined population at a single point in time. Environmental noise studies are almost always cross-sectional studies. Longitudinal studies (studies that measure health effects after a period of exposure to their suggested cause) sufficiently large to address a range of potential health effects, including for example heart disease, are very expensive and require strong justification.

Because the exposure and health outcomes were assessed at a single point in time, none of the included studies was able to provide any indication of the order of events — that is, whether a health outcome first occurred before or after the exposure began. This might mean that a person's self-reported health outcomes were present *before* the person's exposure to wind farms. However,

the sequence of events is not as important in environmental noise studies as in some other epidemiological studies because conclusions can often be made based on what is known historically of exposure and the time of onset of changes in exposed people's health status.

The number of participants in most of the studies was modest. Larger numbers provide greater certainty as to whether any observed association between an exposure and an outcome can be explained by chance. Larger numbers are particularly important if an exposure is likely to have only a small effect on the outcome and when an exposure or health outcome is rare in the study population.

Bias

In scientific studies, the term *bias* is used to describe the effect of an error in the design of a study or an error or problem in the collection, analysis, reporting, publication or review of study data that leads to untrue results.

All studies included as direct evidence had low participation rates, which means that many people who were approached to be part of the study did not participate. There is a high risk of selection bias in a study with a low participation rate, as those who chose to participate in the study may have different exposure and health outcomes to those who did not. For example, people who are unwell may be less likely to participate in studies in general but may be more willing to participate if they live closer to a wind farm, particularly if they knew that the study was about health effects of wind farms.

One study[9] conducted a non-response analysis to determine whether the responses that study participants gave to the questions they were asked differed from the responses given by those who chose not to participate when asked to answer just a few questions. There were no significant differences in exposure to wind farm noise, exposure to background noise or self-reported annoyance depending on participation. However, differences in responses to physical and mental health questions were not assessed.

In many of the studies, the purpose of the research was not masked (i.e. hidden) from participants. Where the studies did attempt to hide the intent of the study from participants, this may not have been effective as participants would probably be aware of the presence of a wind farm in their environment. A lack of successful masking of a study's purpose in this context can contribute to selection bias by making it more likely that a person concerned about wind farms will participate than a person who is not concerned about wind farms. However, effective masking of study intent is difficult in environmental noise studies as they are by necessity conducted in the vicinity of a noise source and often in a climate of controversy about the noise it produces.

All of the health outcomes recorded in the included studies were self-reported. Studies have shown that people often have difficulty in accurately recalling their health details and the timing of onset of their symptoms.[27,28] If this inaccuracy is not random, a false association may be observed. For example, knowledge of a wind farm study's purpose may make people who lived near a wind farm try harder to recall their health details than people who lived further away. This could make people who lived further away from the wind farm appear less sick than those who lived closer, when there is actually no difference.

Confounding factors

When there seems to be an association between an exposure and an outcome, it is important to consider whether this might be due to another factor that is associated with both the exposure and the outcome — such a factor is known as a *confounding factor*. For example, most common physical health conditions (e.g. high blood pressure, diabetes, heart disease) are more common in older than younger people. If people in a study who lived nearer to wind farms were, on average, older than people who

lived further away, physical health conditions would be more common in those who lived close to the wind farm. This association between proximity to wind farms and health might only be due to the age difference and have nothing to do with wind farms. In this example, age is a confounding factor and failure to control for it could lead to an incorrect conclusion that wind farms affect health. We could also be misled, but in the opposite direction, if people who lived nearer to wind farms were instead *younger* and therefore likely to be healthier than people who lived further away.

There are a number of confounding factors that might provide an alternative explanation for any observed association between wind farms and health (such as: socioeconomic status; pre-existing chronic diseases; attitude to, visibility of or economic benefit from wind farms; and negative or positive expectations about the potential effects of wind farms). These factors were not consistently measured in the available studies. When they were, their possible effects on associations between wind farms and health effects were not always taken into account when analysing the results.

In addition, it is possible that variables thought to be confounding factors might instead be effect modifiers, which influence the magnitude of, rather than explain, any true association between wind farms and health. Effect modification can be difficult to uncover, especially in studies with small sample sizes.

Consistency

It is rarely possible to be confident that there is a cause-and-effect relationship based on one study because the results may be affected by chance, bias, or confounding. However, if an observed association in one study is consistently found in other studies (that ideally have been conducted in different ways and by different investigators), this consistency strengthens the case for a cause-and-effect relationship. Similarly, when study results are not consistent, it is more likely that the association is due to chance, bias, or confounding — that is, the association does not indicate a cause-and-effect relationship.

Among the studies reviewed, there was no consistency in finding an association between wind farm exposure and self-reported physical or mental health outcomes. However, there was consistency in showing an association between wind farm exposure and annoyance and disturbed sleep, though the evidence on the latter was less consistent. There was also less consistency in showing an association with poorer quality of life.

Quality of the overall body of evidence

In order to determine the overall quality of the body of evidence on the possible health effects of noise, shadow flicker and electromagnetic radiation, the Reference Group examined each of the individual studies in terms of the factors discussed above (including each study's design, risk of bias and possible confounding factors, as well as the consistency of results between the studies). Based on these factors, all of the individual studies included as direct evidence were considered to be poor quality.

The Reference Group considered the overall body of direct evidence on wind farm emissions and health effects to be weak, as chance, bias and confounding cannot be excluded as possible explanations for any associations observed. Given the limitations of the direct evidence, the Reference Group considered mechanistic and parallel evidence on the health effects of similar emissions from other sources to inform its consideration of the direct evidence and in forming its overall conclusions.

3. Review and assessment of the supporting evidence

3.1 Identification of the supporting evidence

As outlined in Section 1.1 (page 4), supporting evidence was reviewed to gain greater understanding of the characteristics of wind farm emissions, the likely level of exposure to those emissions among people living nearby and whether and how these emissions may affect human health.

The first independent review included specific questions to identify supporting evidence. The independent review of additional evidence did not specifically seek to identify supporting evidence but considered a number of studies identified through the repeat literature search or provided through public consultation submissions or expert review.

Background evidence

The first independent review did not systematically search and select background studies due to the breadth of the topics covered. Rather, key publications in the peer-reviewed literature were identified, particularly those providing up-to-date reviews of relevant evidence, as well as technical reports and analyses prepared by expert panels and environmental health agencies.

A number of studies submitted through the public consultation process or identified by expert reviewers were considered as background evidence in the independent review of additional evidence. These were mostly environmental noise surveys.

Reference Group members also identified additional relevant background evidence for consideration by the Group in developing the Information Paper, based on their knowledge and expertise in the relevant subject matters (including public and environmental health, research methodology, acoustics, sleep and psychology).

Mechanistic and parallel evidence

The review of mechanistic and parallel evidence followed a more structured approach than that of the background evidence in the first independent review. To facilitate the identification of high-level evidence, only peer-reviewed studies were included. Publication databases of peer-reviewed health literature were searched using pre-specified key words and search terms.

Some studies identified through the public consultation, expert review and repeat literature search processes were considered as mechanistic or parallel evidence in the independent review of additional evidence.

3.2 Studies included as supporting evidence

Background evidence included a United States report on the impact of wind farms,[3] discussion of outdoor sound propagation in the vicinity of wind farms,[29] studies of noise and infrasound levels near wind farms and other environments,[30-35] studies of shadow flicker near wind farms[36,37] and World Health Organization (WHO) reports on electromagnetic radiation emissions from household appliances and the environment.[38,39]

Parallel evidence included WHO reports on health effects associated with environmental noise,[40,41] recent studies on cardiovascular outcomes associated with environmental noise[42-44] and with chronic sleep disturbance[45] and epidemiological studies on exposure to electromagnetic radiation.[46]

Mechanistic evidence included laboratory studies on changes in functioning of the human body due to exposure to infrasound or low-frequency noise[47-49] and exposure to shadow flicker.[50]

3.3 Assessment of the supporting evidence

Given the exploratory nature of this component of the independent review and the diverse nature of the publications considered (including technical reports, environmental noise surveys and laboratory studies), no formal quality appraisal of these studies was conducted. However, in formulating the overall conclusions and developing the Information Paper, the Reference Group carefully considered the overall methodological quality of each article or study and the strength of the evidence it provided.

4. Deciding whether wind farms cause health effects

Studies investigating whether living near wind farms might have adverse health effects (direct evidence) can only establish whether there is an *association* between living near wind farms and experiencing a particular health outcome. Generally, an association is "established" if it has been directly observed in several different studies and is judged unlikely to be simply a chance finding. Deciding whether an association between wind farm exposure and a particular health outcome is causal — that is, wind farm exposure *causes* the health outcome — requires more evidence.

- First, it must be clear that the exposure (to wind farms) preceded the outcome (the health effect).
- Second, it must be possible to rule out alternative explanations for the association, including both:
  - bias resulting from the design of the study or the way the study was conducted; and
  - causation by one or more confounding factors associated with wind farm exposure.

Evidence in respect to these points is provided by the *direct* evidence.

- Third, it should be shown:
  - that the association is consistent with other evidence on the effects of the exposure (e.g. noise from some other source); and, ideally,
  - that there is a biological mechanism by which the exposure could cause the health outcome with which it is associated, which is usually established by finding one or more plausible mechanisms in animal studies and then showing that at least one corresponding mechanism is activated by the exposure in humans.

Evidence in these respects is provided by the *supporting* evidence. While causation is sometimes established without supporting evidence of these kinds, it would usually only be if there was very strong direct evidence.

5. Emissions from wind farms

5.1 Noise

Noise is considered an important wind farm emission and is the most studied of the emissions.

Sound and noise perception

Sound travels from a source as a wave (pressure variation) through a medium (e.g. air, water) to a receiver (e.g. the human ear). The number of complete waves passing a given point in one second is the frequency of the wave, expressed in terms of the number of cycles (waves) per second. The unit of frequency is the Hertz (Hz) — 1 Hz is one cycle per second. People sense the frequency of a sound by what they describe as its pitch — e.g. high pitch is used to describe a high-frequency sound and low pitch is used to describe a low-frequency sound. However, what is sensed as pitch is affected by both the level ("loudness") of the sound and its frequency.

Sounds in the frequency range 20–20,000 Hz can normally be heard by humans at sound levels that commonly occur (the upper limit decreases with age).[51] Sound at a frequency lower than 20 Hz is generally termed "infrasound". Human hearing becomes gradually less sensitive as frequency decreases, so a low-frequency sound (lower than 100 Hz) needs to be at a higher level (more physical sound, more "volume") to be heard as loudly as a mid-range frequency (e.g. 1,000 Hz). High-frequency sound reduces in level (becomes quieter) more quickly with increase in distance from its source than low-frequency sound and is attenuated more by walls, doors and windows (i.e. does not pass through as easily). Lower frequency sounds can travel further through most media than higher frequency sounds.[52]

Sound level is measured in a unit called a decibel (dB). Because the ability of humans to hear sound varies with frequency, measurements of noise (which is usually made up of sound of many frequencies) often take this variation into account by giving more weight to frequencies that are more easily heard and less weight to frequencies that are harder to hear at the sound levels at which these frequencies normally occur. This "filtering" is called A-weighting and the sounds measured in this way are expressed in terms of dBA. A-weighted measurements include all frequencies but give less weight in the total measured noise level to low frequencies and infrasound. The G-weighting function, expressed in terms of dBG, gives higher weight to lower frequency sounds and is used when quantifying sound that has a significant portion of its energy in the infrasonic range (below 20 Hz).[30]

A sound or a combination of sounds is usually referred to as noise when it is unwanted. The human perception of sound is only partly related to the acoustic stimulus — that is, to the mix of frequencies in the sound, its level and its other physical characteristics (e.g. variation over time or tonality*). Many other factors are important in determining the perception and reaction to a given sound. These include a person's physical health and psychological state, their attitude towards the perceived source of the sound, their perceived control of the sound, individual variation in how the brain processes sounds when awake and during sleep, and timing (e.g. sounds considered acceptable during the day may be perceived as noise during the night).[54] In NHMRC's review of wind farms and human health, all sound from wind farms is referred to as "noise".

* Noise containing a prominent frequency and characterised by a definite pitch.[53]

Characteristics of wind farm noise

The main noise from modern turbines is "aerodynamic noise" — the "swishing" noise generated by the interaction of flow turbulence with the surfaces of the rotor blades.[11,13,55] This noise is generally in the range of 200–1,000 Hz.[56,57] Wind turbines also produce mechanical noise at a frequency of 20–30 Hz (for a 1,500 kilowatt turbine).[3]

Wind farm noise is said to be amplitude modulated when its level (loudness) exhibits periodic fluctuations at a rate corresponding to the frequency at which a rotor blade passes a fixed point. For a modern Multi-megawatt three-bladed wind turbine, the typical blade-passing frequency would be 0.8 Hz (slightly less than once a second). In some wind farm sites, the resultant variation in the overall A-weighted sound pressure level exceeds 6 dB. This noise has been described as being more impulsive in character and better described as a "whoosh" or "thump" than as a "swish", with a shift in the dominant frequency range to around 400 Hz.[58]

The occurrence of amplitude modulation depends on a complex range of factors, including local atmospheric conditions, topography, turbine blade design and the way in which they are controlled. A particular turbine type may exhibit the effect in one site but not in another. The effect varies greatly with distance, wind direction and over time, including whether it is day or night time (it may be more common in the evening or night).[58]

When multiple wind turbines are producing sound, the total sound pressure level at a particular location is affected by the sequence of the arrival of the sound (referred to as coherence). For example, if each of the turbines' blades are turning at the same time and are the same distance from the location, the sound from all the turbines would arrive at the same time, increasing the "loudness" of the sound. Amplitude modulation may be enhanced when this coherence effect occurs.[59] However, if some turbines are further away or located at 180 degrees, there will be "cancellation" of some of the sound. These effects also vary depending on meteorological conditions, distance and location.

Wind farm noise is complex and highly variable in character (e.g. tonality, frequency content and impulsivity). These characteristics and the duration of exposure influence the way in which wind farm noise is perceived. Perception is also influenced by characteristics of the person perceiving the noise — people who detect and recognise wind farm noise more easily may find it more annoying[60] and people living in quiet environments may be more sensitive to low-frequency noise.[35]

In wind farm noise studies, the predicted or estimated noise level from a wind farm based on a mathematical model can only consider the sound level of the noise source, distance of the receiver, siting of each source relative to each other, topographical features and meteorological conditions. It is not yet possible to predict the complex and highly variable characteristics of wind farm noise (e.g. amplitude modulation). However, when actually measuring noise from a wind farm, the total noise is assessed rather than the noise from each individual turbine. Therefore amplitude modulation and other unique characteristics of wind farm noise would be included in the measurements.

While wind farm noise is difficult to measure in the presence of background noise, its level is generally in the range of 30–45 dBA at a distance of 500–1,500 m from the wind farm.[29] Under occasional and distinct circumstances (depending on the size and output of individual turbines, wind farm size and layout, terrain and meteorological and atmospheric conditions, including wind speed and wind direction), noise levels may be considered disturbing at 500–1,500 m from wind farms. Although individuals may perceive aspects of wind farm noise at greater distances, it is unlikely that wind farm noise would be considered disturbing at distances of more than 1,500 m. At this distance, wind farm noise is usually below 30–35 dBA, below the noise levels of household devices and similar to a quiet residential area (see Figure 2, page 17). [29,41,54]

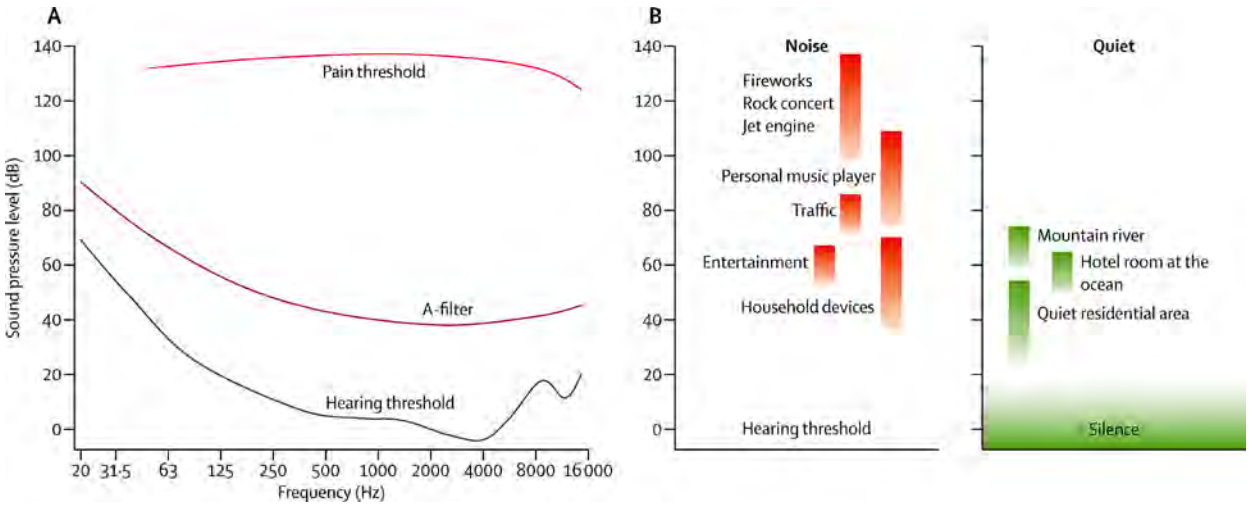


Figure 2: Typical sound pressure levels for common environmental noise sources. (A) The sensitivity of the auditory system depends on sound frequency and sensitivity is highest between 2000 Hz and 5000 Hz (green line). The A-filter (dark red line) is a frequency-weighting of sound pressure levels that mimics the sensitivity of the auditory system (e.g. low-frequency sounds contribute little to the A-weighted dB level). (B) A-weighted sound pressure levels for several environmental sounds, emphasising that whether or not a sound is perceived as noise depends largely on the context and the individual, and is only partly determined by its sound pressure levels.

Source: Reprinted from The Lancet, Volume no. 383(9925), Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S et al, Auditory and non-auditory effects of noise on health (Figure 1),[54] page no. 1,325–32, Copyright (2014), with permission from Elsevier.

Evidence suggests that the component of wind farm noise that is low frequency noise may increase with the power-generating capacity of turbines[34] and under certain wind farm operating and weather conditions.[35] Infrasound measured in the vicinity of wind farms (at distances of 85–7,600 m) has been reported at levels significantly below the accepted audibility threshold of infrasound frequencies (i.e. greater than 85 dBG)[32] both outside[30,31,33,34] and inside residences[30,32-35] and levels are similar to those at other locations (e.g. at the beach, in the vicinity of a coastal cliff, near a gas-fired power station and in a city centre away from major roads).[31] In some circumstances low-frequency noise may result in vibration in some residences in the form of rattling of windows or objects on shelves.[61]

5.2 Shadow flicker and other visual stimuli

Shadow flicker, as it relates to wind farms, is defined as the flickering effect caused when rotating wind turbine blades intermittently cast moving shadows on the ground, resulting in alternating changes in light intensity.

Exposure to flicker from a wind turbine depends on its hub height and blade diameter, the wind direction, geographical location and the direction and height of the sun (which is affected by the time of day and time of year).[36,37] Shadow flicker is generally present only at distances of less than 1.4 km from wind farms.[3]

Warning lights are required on some wind turbines in Australia for aviation safety. These are generally a pair of red lights that flash simultaneously[62] and could be perceived as annoying.

5.3 Electromagnetic radiation

Electromagnetic radiation broadly refers to combinations of electric and magnetic waves. Electromagnetic radiation is emitted by a range of common domestic appliances (e.g. vacuum cleaners, microwave ovens, colour televisions and mobile phones).

Extremely low-frequency electromagnetic radiation is the only potentially important electromagnetic emission from wind farms that is relevant to health.[63] The available information suggests that the level of extremely low-frequency electromagnetic radiation close to wind farms is lower than that found close to common household appliances when in use[38,64] and much lower than the average level measured inside and outside suburban homes.[38] However, levels are high near high-voltage power lines transmitting the electricity that wind farms generate, as they are near any power lines of equivalent voltage.[64]

6. Findings of the review

6.1 Noise

6.1.1 Direct evidence

This section describes associations for which there is direct evidence in the reviewed literature. It is important to note that all the individual studies that provided direct evidence were considered to be of poor quality and no detailed critical appraisal of each mentioned paper is included in this descriptive section. Overall, wind farm noise was not directly measured at participants' homes in any of the studies included as direct evidence. Rather, people's exposure to wind farm noise was estimated based on how far they lived from the wind farm (proximity) or by using mathematical models to estimate the level of sound where they lived. The mathematical models take into account a range of factors including sound output from the turbines and distance to the house. In addition, even where consistent associations were found between estimated wind farm noise and effects such as annoyance, it was not possible to tell whether the noise was driving the association or whether the association could be explained by one or more other factors that are more common among people living close to wind farms (such as attitude to, visibility of or economic benefit from wind farms).

The overall conclusions of the Reference Group about wind farm emissions and the effects examined in these studies are presented in Section 6.4 (see page 23).

Physical health

Seven studies assessed self-reported physical health and estimated level of wind farm noise[7,10-13,18] or proximity to wind farms.[14,15,21] Collectively these studies reported on chronic diseases, cardiovascular disease, ratings of general health, blood pressure, headaches, tinnitus, vertigo, hearing loss and whether participants had sought help from a doctor.

The results of one study suggested a link between estimated wind farm noise and tinnitus[10,13] and another study suggested a link between wind farm noise and increased prevalence of diabetes.[10,11] However, other studies that looked at tinnitus[7,10,11,14,21] or diabetes[7,10] did not find a significant association. One study found an association between proximity to wind farms and self-reported vertigo.[21] No links were found between estimated wind farm noise or distance from wind farms and any of the other physical health outcomes.[7,10,11,13-15] A small survey with a very low response rate suggested that reporting of physical symptoms was more closely related to the perception of noise than to actual noise exposure.[18]

Mental health

Five studies assessed aspects of self-reported mental health (stress, irritability, psychological distress, anxiety and depression) and estimated level of wind farm noise[7,9-11,13] or proximity to a wind farm.[14,16] Four studies found no significant differences in the mental health of participants depending on noise level or distance.[7,9-11,13,14] Three of these studies masked the study's purpose.[9,11,13] One study reported that individuals who lived closer to wind farms had lower mental health scores on a self-completed health questionnaire. However, the purpose of that study (being to investigate the health effects of wind farms) was explained to participants.[16]

One study found that psychological distress was significantly related to annoyance and not sound level.[9]

Annoyance

Annoyance is a negative response that does not necessarily affect health status but may result in stress, which over the longer term may affect physical and mental health.[54,65]

Six studies assessed the association of annoyance with exposure to estimated wind farm noise[7,9-13,17,19,20] or proximity to a wind farm.[8,15] The studies all reported an association between annoyance and higher estimated levels of wind farm noise[7,9-13,17,19,20] or living closer to a wind farm.[8,15] Rates of annoyance differed greatly between studies depending on the estimated noise exposure, definition of annoyance and whether the purpose of the study was masked from participants.

Further analysis of three studies[7,10-13,17] found that, in comparison to other sources of environmental noise, annoyance due to wind farm noise occurred at relatively low noise exposure levels.[25] Reported annoyance was higher when wind turbines were visible from the dwelling and lower when participants received economic benefit from the wind farm.[25] Annoyance reported by participants may also have been influenced by factors other than the noise produced by wind farms, such as the participants' demographic, psychological and biological factors, their attitudes and perceived degree of control, and situational factors (including day and time, activity disturbance, terrain and features of the dwelling).[66]

Sleep

Noise at night can disturb sleep[41] and objectively measured[67] chronic sleep disturbance is known to have an effect on health.[54]

The association of wind farm noise with self-reported sleep quality was assessed in nine studies.[7-11,13-16,19,21] Eight studies reported poorer sleep (mostly disturbed sleep and poor sleep quality) among people exposed to higher estimated levels of wind farm noise[7,9,10,13,19] or living closer to wind farms.[8,14-16,21] One of these studies asked participants whether they slept better when they were away from wind farms and most participants said they did sleep better.[16]

However, sleep disturbance in the studies was not objectively measured and therefore it was not clear whether it would be sufficient to affect health.

The reported associations of wind farm noise with sleep quality were generally weak. In some of the studies the association between estimated wind farm *noise* and sleep quality was weaker than the association between wind farm noise *annoyance* and sleep quality.[9-11,13]

Only some of the studies considered possible confounding factors in their analysis. In one study that did consider possible confounding factors participants who did *not* benefit economically from wind farms reported more sleep interruption than others.[7] This was reported regardless of how close they were to the wind farm. Therefore it is possible that factors other than noise (such as economic benefit) could explain or modify the apparent association between wind farm proximity and sleep disruption.

Quality of life

Quality of life is a broad and holistic construct that measures health and wellbeing across multiple domains, including those that are physical, mental and social. It refers to a person's view of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns.[68] Quality of life may be affected by physical health, psychological state, level of independence, social relationships and features of the environment.[68] Measurement of quality of life is generally subjective. Poor quality of life may be an indicator of poor health.

Four studies assessed quality of life and proximity to wind farms.[14-16,23,24] Only one study attempted to mask the purpose of the study from participants and used a formally validated questionnaire.[15] This study found an association between proximity to wind farms and poorer overall quality of life. A second study conducted in this community 2 years later (using the same study design but a different sample of the population) made the same observation.[23]

Two other studies used author-formulated questions and did not mask the purpose of the study. In one of these studies the majority of people reported that their quality of life had altered since living near a wind farm, regardless of how close they lived to the wind farm.[14] The other study reported that more residents living close to a wind farm wanted to move away than residents living further from a wind farm.[16] The studies did not explore whether these associations could be explained by other factors (e.g. annoyance at the wind farm, visibility of the wind farm or economic benefit from the wind farm).

One study using a validated questionnaire found that quality of life was higher for participants whose residences were closer to a wind farm.[24] Masking was not mentioned in this study and the participation rate was not reported. Adjustment for socioeconomic status and health variables did not explain the inverse relationship. Information on whether participants benefitted economically from the wind farm was not collected.

6.1.2 Parallel and mechanistic evidence

Noise in other environments

Most of the studies into the health effects of environmental noise have been about exposure to noise from road traffic, aircraft or rail[3] and generally examine exposure to noise at levels in the order of, or higher than, that expected from wind farms at 500 m.

High levels of noise from sources other than wind farms have been consistently associated with hearing loss, disturbed sleep and annoyance.[40,54] Prolonged exposure to high levels of environmental noise (greater than 55 dBA) may also contribute to the prevalence of high blood pressure and heart disease.[40,42-44] A poorly understood condition referred to as "vibroacoustic disease" has also been reported in people exposed, mainly occupationally, to high levels of low-frequency sound and infrasound. The condition is described as being "characterised by the abnormal proliferation of collagen and elastin, in the absence of an inflammatory process".[69] Its relationship to low-frequency sound and infrasound has been inconsistently corroborated by independent research.[70,71]

The WHO reported a number of effects on sleep when night noise was in the range of 30–40 dBA (measured outside).[41] These include body movements, awakening, self-reported sleep disturbance and arousals. The intensity of the effect varies with the nature of the source of the noise and the number of noise events. Vulnerable groups (e.g. children, people who are chronically ill and elderly people) are more susceptible to effects on sleep. However, even in the worst cases, the effects seem modest.[41] A recent meta-analysis concluded that people consistently reporting 5–6 hours or less sleep a night have a higher risk of heart disease and stroke.[45]

Prolonged noise-related annoyance may also cause health effects,[54] as evidence suggests that stress pathways may be active in annoyed individuals[66] and psychological stress may be a risk factor for cardiovascular disease.[65]

There is no evidence to suggest that the health effects from wind farm noise would differ from health effects of other noise sources at similar levels. Based on the studies referred to above, wind farms would be unlikely to cause health effects at distances of more than 500 m, where noise levels are generally less than 45 dBA. At this distance, effects on sleep are likely to be modest at the population level. At distances of more than 1,500 m from wind farms, where the wind farm noise level may be in the order of 30–35 dBA, sleep disturbance is unlikely. There is insufficient evidence to establish whether self-reported sleep disturbance associated with wind farm noise is of the duration and intensity known to cause health effects.

The table below shows a comparison of wind farm noise with other typical environmental noise sources.

Wind farm noise and other typical sources of environmental noise	Approximate noise levels (dBA)
Traffic	70 – 85
Household devices	35 – 70
Wind farm at 500 m to 1,500 m	**30 – 45**
Wind farm beyond 1,500 m	**30 – 35**
Quiet residential area	25 – 55

Table 1: Approximate levels from wind farm noise and other typical environmental noise sources

Source: Data adapted from Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S et al., 2014 [54] and Bullmore A & Peplow A, 2012[29].

Studies have shown that infrasound from other environmental noise sources is at similar levels to that from wind farms.[30,31] As infrasound is a component of noise, the evidence summarised above applies as much to infrasound as it does to other sound frequencies from wind farms.

Human laboratory studies

Laboratory studies have investigated changes in functioning of the human body when people are exposed to infrasound or low-frequency noise. One study suggested that high levels of low-frequency noise and infrasound may lead to small and inconsistent changes in blood pressure, pulse or heart rate.[47] High levels of low-frequency noise may also cause temporary hearing loss.[48,49] These studies involved higher levels of noise (greater than 90 dB) and shorter exposures than those experienced in the proximity of wind farms and the characteristics of wind farm noise were not fully replicated.

Other laboratory studies have suggested that both negative and positive expectations of the effect of infrasound may influence its perception.[72,73]

6.2 Shadow flicker and other visual stimuli

6.2.1 Direct evidence

No studies were identified that assessed the health effects of shadow flicker or other visual stimuli from wind farms. One small study with a high risk of bias reported that people who lived within 5 kilometres (km) of a wind farm were more likely to notice and be annoyed by shadow flicker than those who lived 5–10 km away.[8]

Although of no specific relevance to shadow flicker, a small study[22] examined the association of annoyance with illuminated aircraft warning markers on wind turbines and found that the markers contributed less to annoyance than other characteristics of wind farms, such as noise.

6.2.2 Parallel and mechanistic evidence

It is known that flashing lights can trigger seizures among people with a rare form of epilepsy called photosensitive epilepsy. The risk of shadow flicker from wind farms causing an epileptic seizure is estimated to be less than 1 in 10 million in the general population[74] and 17 in 1 million among people at risk of photosensitive epilepsy.[36]

People exposed for short periods to simulated wind turbine shadow flicker in a laboratory have shown some evidence of impaired cognition and a physiological stress response.[50]

6.3 Electromagnetic radiation

6.3.1 Direct evidence

No studies were identified that specifically assessed the health effects of electromagnetic radiation from wind farms.

6.3.2 Parallel and mechanistic evidence

Concerns regarding the safety of exposure to electromagnetic radiation were raised with the publication of a study reporting a link between childhood leukaemia and extremely low-frequency electromagnetic radiation exposure from electricity transmission lines.[46] Subsequent research has looked for possible links between occupational exposure to extremely low-frequency electromagnetic radiation and cancer and cardiovascular, neurological, psychological or reproductive conditions in adults. The results of these studies have been inconsistent and no conclusions can be drawn about a cause-and-effect relationship between extremely low-frequency electromagnetic radiation exposure and human health effects.[75] The exposures in these studies were considerably higher than electromagnetic emissions from wind farms.

Exposure to extremely low-frequency electromagnetic radiation can induce electrical currents in human tissue — the significance of these currents to human health is not known.[39]

The level of extremely low-frequency electromagnetic radiation close to wind farms is lower than the average level measured inside and outside suburban homes (see Section 5.3, page 18).

6.4 Conclusions

After careful consideration and deliberation, NHMRC concluded that there is no consistent evidence that wind farms cause adverse health effects in humans. This finding reflects the results and limitations of the direct evidence and also takes into account the relevant available parallel evidence on whether or not similar noise exposure from sources other than wind farms causes health effects.

NHMRC found no direct evidence that exposure to wind farm noise affects physical or mental health. The few associations reported by individual studies may have been due to chance. The parallel evidence indicates that there is unlikely to be any significant effects on physical or mental health at distances greater than 1,500 m from wind farms.

NHMRC found consistent but poor quality direct evidence that wind farm noise is associated with annoyance. While the parallel evidence suggests that prolonged noise-related annoyance may result in stress, which may be a risk factor for cardiovascular disease, annoyance was not consistently defined in the studies and a range of other factors may have contributed to its reported association with wind farm noise.

The direct evidence of an association between wind farms and sleep disturbance is less consistent and also of poor quality. While chronic sleep disturbance is known to affect health, it was not objectively measured in the wind farm studies and may not have been sufficient to affect health. Parallel evidence suggests that sleep disturbance is unlikely at distances of more than 1,500 m from wind farms.

The direct evidence on an association between proximity to wind farms and poorer quality of life is also less consistent and of poor quality. Measurement of quality of life is generally subjective and the studies did not explore whether the reported associations could be explained by other factors.

Observation of associations between wind farms and these effects does not necessarily mean that wind farms caused them. Given the poor quality of the evidence, bias of different kinds and confounding factors are possible explanations for the associations observed.

When building a body of scientific evidence, it is difficult to establish absence of an outcome (i.e. a negative conclusion, such as that an exposure does not cause health effects). Thus lack of consistent evidence that wind farms affect human health may not mean that wind farms have no health effects. While parallel evidence indicates that significant health effects are unlikely at distances greater than 1,500 m, it might simply be that the research done has been of insufficient quality or statistical power to show an effect, particularly where the study has a small number of participants.

7. Areas for further research

Further evidence is needed to explore the relationships between noise at varying distances from wind farms and effects such as annoyance, sleep and quality of life. Research is also required to investigate the broader social and environmental circumstances that may influence the reporting of health effects in people living near wind farms.

7.1 Engagement with the community

Gathering sufficient quality evidence in these areas may assist governments and planning authorities to make evidence-based decisions regarding wind farm policy, planning and development. Wider engagement and participation, including by the community, in the various stages of research would be beneficial in ensuring that research is appropriately targeted to the community's areas of concern. This could include community members being involved in deciding what to research, deciding how to conduct the research, overseeing conduct of the research, disseminating the findings and deciding what to research next.[76] Researchers are encouraged to demonstrate community engagement and participation in the development of their research proposals, particularly to identify the specific concerns of individuals and communities living in proximity to wind farms.

7.2 Themes for further research

The Reference Group has identified a number of themes for further research. It is important that research measuring and characterising wind farm noise exposure is completed prior to undertaking research into health effects and possible interventions. Three main themes have been identified to provide high-level guidance on the areas for research to address current gaps in the evidence. These areas are not exclusive and research should also allow for innovative proposals that are broadly relevant to these themes.

The three themes for further research are discussed below.

7.2.1 Improve the measurement of noise

The studies identified in the independent reviews did not directly measure wind farm noise at participants' homes. People's exposure to wind farm noise was estimated based on how far they lived from the nearest wind farm (proximity) or by using mathematical models to estimate the level of sound where they lived. However, it is difficult to estimate the level of noise from wind farms in the presence of background noise.

Where consistent associations were found between estimated wind farm noise and an effect, such as annoyance, it was not possible to tell whether *noise* was driving the association or whether the association could be explained by one or more other factors that are more common among people living in close proximity to wind farms (such as attitude to, visibility of or economic benefit from wind farms).

The Reference Group considers that further research is required to characterise wind farm noise (audible, low-frequency and infrasound) at distances ranging from 500 m to 3 km and beyond, in different terrains and under varying weather conditions. These outcomes may inform whether a "wind farm signature" can be developed and validated as a specific indicator of wind farm noise.

Infrasound is considered by some to be an important component of the noise from wind farms. The Reference Group considers that there is a need to develop standardised methods to measure infrasound indoors and outdoors and at various distances from a wind farm (ranging from 500 m to 3 km and beyond). This would ensure there is consistency in the measurement of infrasound from wind farms and aid interpretation of the body of evidence on the effects of wind farm noise. Indoor measurement of vibration associated with low-frequency noise may also contribute to understanding of the effects of wind farm noise.

Field studies to establish the characteristics of noise that are exclusive to wind farms (if any) and to consider how wind farm noise varies over the course of the day, in different terrains, under different weather conditions and with further increases in distance would be useful approaches to address this issue. Further, an assessment of the subjectively measured human perception of wind farm noise (including audible noise, low-frequency noise and infrasound) may improve understanding of whether wind farm noise is perceived differently from other similar noise sources.

7.2.2 Examine the relationship between wind farm noise and health effects

All the studies identified as direct evidence in the independent reviews used self-reported measures of health outcomes to determine whether there was any association between these outcomes and exposure to wind farm emissions. Given the lack of objective health measurements in these studies, bias cannot be excluded as an explanation for any apparent association. In addition, the measurement of annoyance, sleep disturbance and mental health in relation to wind farm proximity lacked the consistent use of validated questionnaires.

Field studies that include objectively measured physiological and biochemical characteristics (including sleep) along with an individual's self-reported physical and psychological status (including annoyance and stress) and consistently use validated self-reporting instruments are required to address methodological shortcomings in the existing evidence. Measurements of these variables should be made in relation to objectively recorded noise from wind farms (measured inside and outside residences) and exposure in the field to simulated wind farm noise generated by a loudspeaker. Another possibility would be measurement of physiological and biochemical characteristics and assessment of self-reported physical and psychological status before and after a period of removal from the wind farm environment.

Laboratory studies would also be useful to examine the effects of validated wind farm noise on objectively measured physiological and biochemical characteristics. These findings could then be considered alongside comparable field studies.

7.2.3 Investigate the social and environmental circumstances

The Reference Group recommends further investigation of the broader social and environmental circumstances that influence annoyance, sleep disturbance, quality of life and health effects that are reported by residents living in proximity to wind farms.

Factors that influence changes to health effects may include people's expectations of their environment, perceived loss of control, aesthetics and impacts on visual landscape, impacts on land values, uneven distribution of financial benefits, local community relationships and exposure to other noise sources (e.g. road traffic and wind noise).

Further research would improve the understanding of the potential confounding or modifying effects of these factors on the relationship between objectively recorded exposure to validated wind farm noise and:

- an individual's self-reported physical and psychological status (including annoyance); and
- an individual's objectively measured physiological and biochemical characteristics.

This could be achieved through a program of psychosocial research to investigate, develop and test interventions that might reduce the impacts of wind farm developments on nearby residents. This research may assist in developing possible policy or consultative interventions that may address the above-mentioned broader factors and thereby reduce the reported health effects of wind farms.

7.3 Other research-related issues

In addition to further research, expert assessment of some existing research on human physiological responses to noise is needed. Community concern and some research on possible health effects of wind farms have tended to focus on low-frequency sound and infrasound as likely causes of harm. Some physiological or pathological mechanisms have been suggested to explain how these sound frequencies in wind farm noise might lead to human health effects, such as through unique effects on the cochlea[77] or the more systemic "vibroacoustic disease".[69] Closer examination of these hypotheses was outside the scope of work of the Reference Group. Expert analysis of the body of evidence exploring human physiological and suggested pathological responses to noise may assist in determining the plausibility of the mechanisms that have been proposed and their relevance to the wind farm context. This work may include further assessment of existing animal studies investigating possible mechanisms whereby wind farm emissions could cause human health effects, which was also beyond the scope of the Reference Group's work. This will inform whether further research on these possible physiological and pathological mechanisms is warranted to improve understanding of the effects of infrasound and low-frequency sound from wind farms.

Appendices

A Membership and terms of reference of the Reference Group

Membership

Members	Area(s) of expertise	Affiliation
Professor Bruce Armstrong (Chair)	Environmental epidemiologist	Emeritus Professor School of Public Health The University of Sydney
Professor Michael Abramson	Environmental epidemiologist and respiratory physician	Professor of Clinical Epidemiology Epidemiology and Preventive Medicine School of Public Health and Preventive Medicine Monash University
Professor Ronald Grunstein	Specialist physician in sleep medicine	Professor of Sleep Medicine Woolcock Institute of Medical Research Central Clinical School The University of Sydney and Royal Prince Alfred Hospital
Professor Debra Rickwood	Health and community psychology	Professor of Psychology Faculty of Health, University of Canberra Chief Scientific Advisor headspace National Youth Mental Health Foundation
Professor Wayne Smith	Environmental epidemiologist	Director Environmental Health Branch, NSW Health Conjoint Professor of Epidemiology University of Newcastle Honorary Professor of Public Health The University of Sydney
Dr Norm Broner	Acoustic consultant	Principal, Broner Consulting (Previously Practice Leader Acoustics, Noise and Vibration Jacobs)
Dr Elizabeth Hanna	Epidemiologist	Fellow National Centre for Epidemiology and Population Health ANU College of Medicine, Biology and Environment
Anne McKenzie	Consumer Advocate	Consumer Advocate The University of Western Australia's School of Population Health and the Telethon Kids Institute
Observers		
Peter Mitchell		Honorary Chairman Waubra Foundation Member of Board of Governors Florey Neuroscience Institute Patron, Children First Foundation
Russell Marsh		Policy Director Clean Energy Council

Terms of reference

1. The Wind Farms and Human Health Reference Group will guide the development of a systematic review to determine if new evidence exists in the peer reviewed scientific literature on possible health effects of wind farms, by providing advice to the Office of NHMRC on the:
   a. scope and questions the systematic review will address;
   b. methods to identify relevant published guidelines and systematic reviews; and
   c. methods to evaluate relevant published guidelines and systematic reviews.
2. The Wind Farms and Human Health Reference Group will consider the outcomes of the review and use these finding to:
   a. inform updating NHMRC's Public statement: wind turbines and human health; and
   b. identify critical gaps in the current evidence base.
3. The Wind Farms and Human Health Reference Group will provide NHMRC's Prevention and Community Health Care Committee with a report on wind farms and human health, which is to include advice on the systematic review outcomes, updating the Public Statement and possible need for further research, for consideration before recommendation to Council.

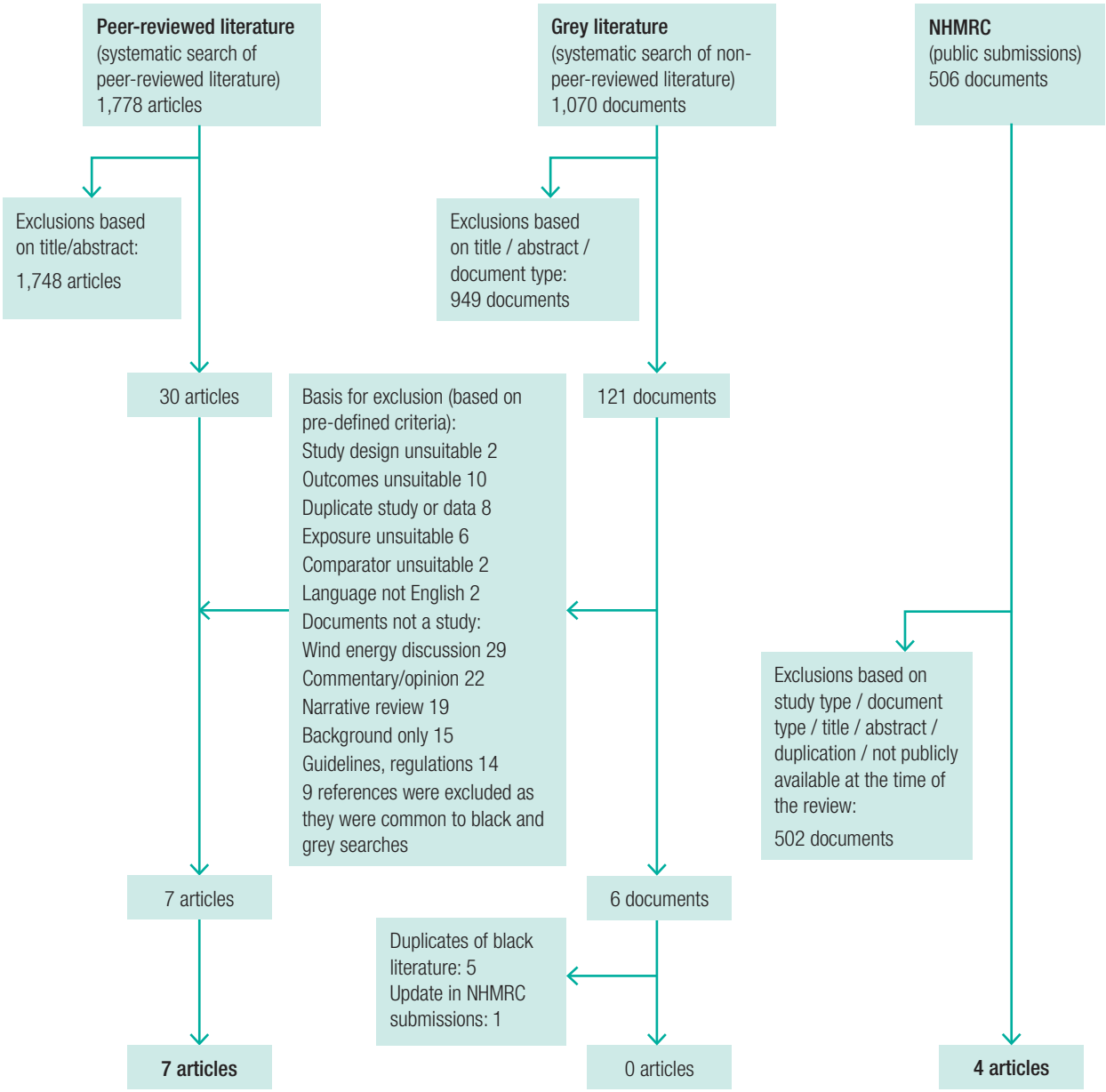
B Quality assurance processes

Rigorous quality assurance processes support the development of all NHMRC health advice. The quality assurance processes used to support the quality of the independent reviews of the evidence and the Information Paper are outlined below.

- *Reference Group observers* — Two observers were appointed to the Reference Group to observe process. The observers did not contribute to the scientific discussions or decision-making processes of the Reference Group. While bound by a deed of confidentiality with respect to the details of the Reference Group's deliberations, the observers are free to comment in general terms on the process they observed following publication of this Information Paper.
- *Reference Group declaration of interests* — As part of their formal appointment to the Reference Group, each member and observer was required to disclose any factors that may cause or be perceived to cause a conflict of interest with their duties as members of the Reference Group. The declared interests of all Reference Group members and observers have been published on NHMRC's website. The Reference Group Chair reviewed each member's declared interests and no unmanageable conflicts were identified. While some members of the Reference Group had relevant interests, most members did not. All discussions of the group were robust and open and decision-making was consensus-based.
- *Methodological review* — Independent reviewers from the National Collaborating Centre for Environmental Health in Canada examined the methodological quality of the report of the first independent review to ensure that the review followed the systematic and rigorous approach documented in the review protocol. The methodological reviewers were appropriately qualified in systematic review processes and had previous experience in reviewing the scientific evidence on possible health effects of wind farms. The methodological review team completed a declaration of interest process before being appointed by NHMRC and no conflicts of interest were identified. The independent reviewers assessed the methodological quality of the review as high.
- *Public consultation* — The draft Information Paper was released for public consultation, accompanied by the supporting independent review report. The public consultation process allowed members of the public to make submissions about the document, comment on the evidence-based approach that was undertaken and provide any relevant additional evidence for consideration. The draft Information Paper was revised in light of the submissions that were received during public consultation.
- *Expert review* — In parallel with public consultation, the draft Information Paper underwent expert review to ensure that the evidence was appropriately interpreted and synthesised. The expert reviewers were asked to evaluate the appropriateness of the conclusions based on the existing body of evidence. In addition, the expert reviewers were asked to consider whether:
  - the rationale applied in examining the evidence was clearly explained;
  - the evidence was accurately translated into the draft Information Paper; and
  - the conclusions in the document aligned with their understanding of the latest evidence in their specific area of expertise.
- NHMRC selected a number of Australian and international experts in the fields of acoustics, aerospace engineering, mental health, sleep, epidemiology and environmental health to conduct the expert review. Before being appointed, potential expert reviewers were required to declare any interests that may be perceived to cause a conflict with their role as an expert reviewer.
- *Consideration by the Council of NHMRC* — The consultation draft and final Information Paper were considered by the Council of NHMRC for its recommendation to the Chief Executive Officer that the documents be released. The Council has a broad range of experience and expertise in health and medical research. Council's final approval of NHMRC health advice documents ensures that the checks and balances at all stages of the process have been met and that any material issued by NHMRC is evidence-based, robust and meets international standards.

C Process of selecting literature for inclusion

Systematic literature search in first independent review (material published 1981 – October 2012)



Study design unsuitable — qualitative study design or case reports

Outcomes unsuitable — sound or noise level measures, sound directivity, attitude or other non-health-related outcomes

Duplicate study or data — the study duplicates the work or data reported in a previously identified and included study

Exposure unsuitable — exposure is noise from sources other than wind farms

Comparator unsuitable — comparisons between groups exposed to different noise sources

Figure 3: Process of selecting literature for inclusion in the first independent review

Source: Adapted from the report of the independent review,[1] Figure 1, page 43.

Repeat systematic literature search in independent review of additional evidence (material published October 2012 – May 2014)

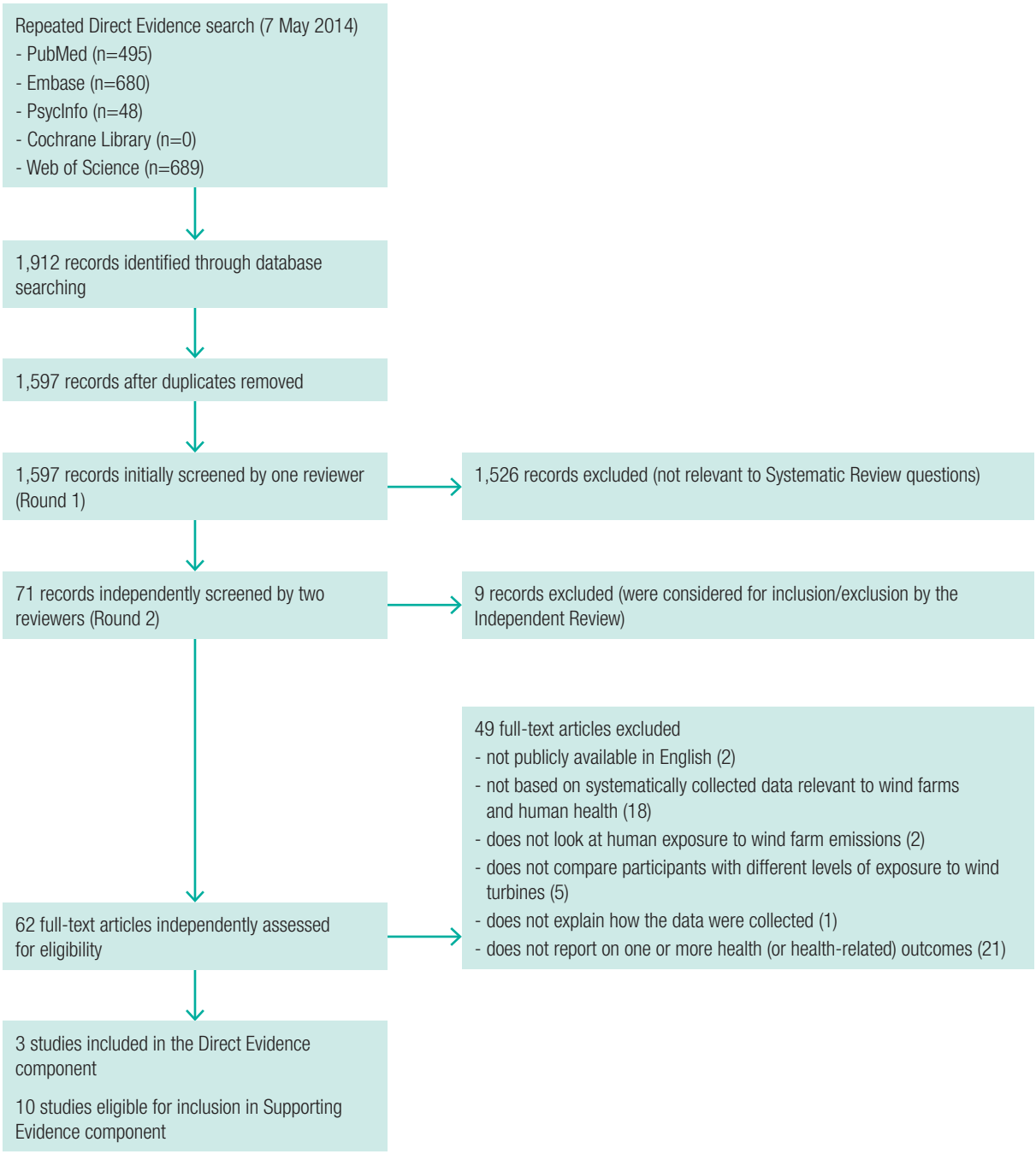


Figure 4: Process of selecting material from repeat systematic literature search for inclusion in the independent review of additional evidence

Source: Adapted from the report of the independent review of additional evidence,[2] Figure 1, page 7.

Assessment of submitted literature in independent review of additional evidence

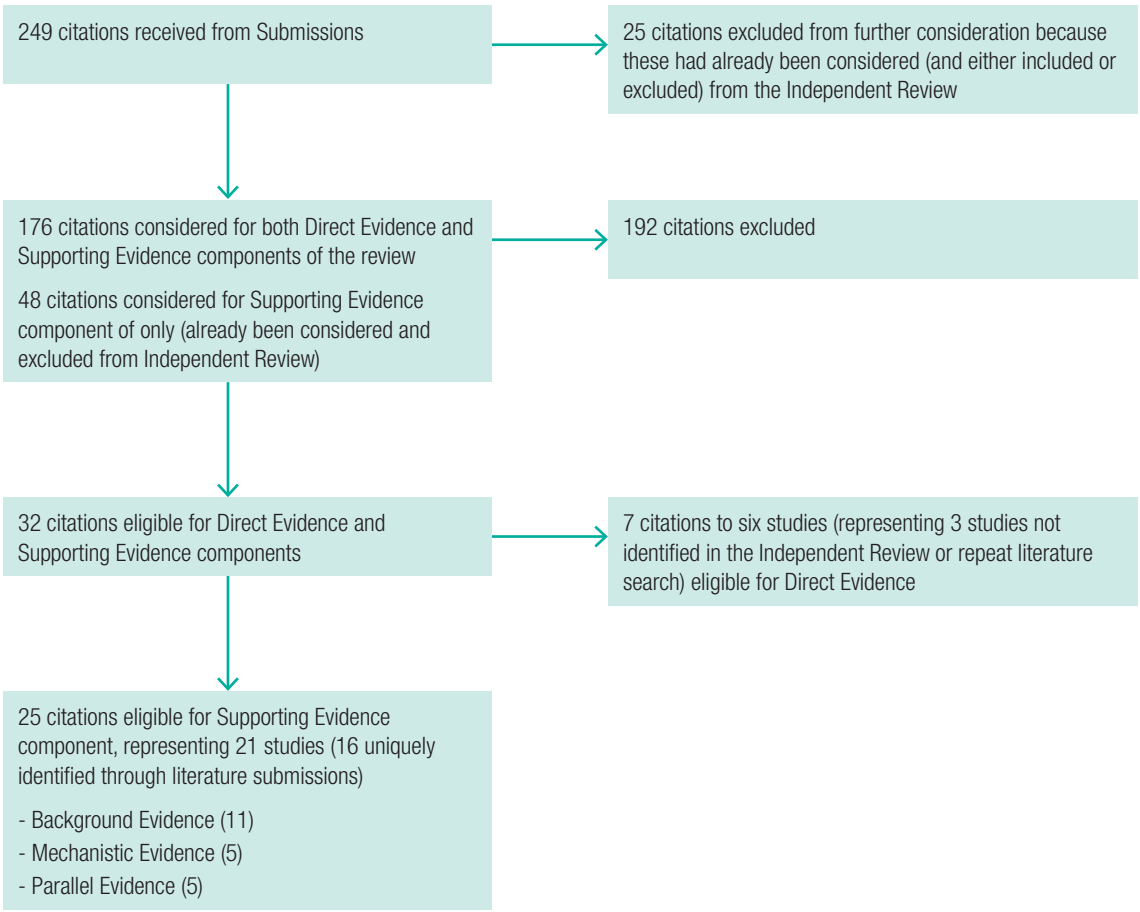


Figure 5: Process of selecting submitted literature from public consultation and expert review for inclusion in the independent review of additional evidence

Source: Adapted from the report of the independent review of additional evidence,[2] Figure 2, page 9.

Glossary

A-weighted decibels: Noise levels adjusted to represent the response of the human ear (expressed as dBA).

Acoustics: The science that deals with the study of the generation, transmission and reception of sound, ultrasound and infrasound.

Aerodynamic sound: For wind turbines, the sound generated by the interaction of the blade trailing edge, tip or surface with turbulent air flow.

Annoyance: An unpleasant mental state characterised by effects such as irritation and distraction from one's conscious thinking.

Association:* Statistical dependence between two or more events, characteristics or other variables.

Bias:* The effect of an error in the design of a study or an error or problem in the collection, analysis, reporting, publication or review of study data that leads to untrue results.

Chance:* The probability that an event will happen[#] or, in a phrase such as "happened by chance", the occurrence of events in the absence of any obvious intention or cause.

Confounding:* The distortion of a measure of the effect of an exposure on an outcome due to the association of the exposure with other factors (confounders) that influence the occurrence of the outcome.

Cross-sectional study:* A study that examines the relationship between diseases (or other health-related characteristics) and other variables as they exist in a defined population at one particular time.

Decibel: A unit of measure used to express sound pressure amplitude associated with a sound, calculated as the logarithmic ratio of sound pressure level against a reference pressure, multiplied by 20 (expressed as dB).

Direct evidence: Evidence directly linking an exposure with a health outcome of interest.

Economic benefit: A benefit to a person, business or society that can be expressed numerically as an amount of money that will be saved or generated as the result of an action.

Effect modifier:* A factor that, when it varies, modifies the effect of another factor on an outcome with which it is causally associated.

Electromagnetic radiation: Radiation that is a combination of electric and magnetic waves (such as x-rays, ultraviolet rays, infrared rays, visible light and radio waves) transmitted in a wave-like pattern as part of a continuous spectrum.

Emission: For wind farms, recognised emissions include noise (including infrasound and low-frequency sound), shadow flicker and electromagnetic radiation.

Epidemiology: The study of the patterns, causes and effects of health and disease conditions in human populations.

* Adapted from the International Epidemiological Association *Dictionary of epidemiology*.[78]

[#] The International Epidemiological Association definition[78] states "possibility" rather than "probability". However, for the purposes of the systematic review "probability" was preferred.

Epilepsy: A neurological condition marked by sudden recurrent episodes of sensory disturbance, loss of consciousness or convulsions, associated with abnormal electrical activity in the brain.

Exposure: For this review, exposure relates to being in the vicinity of wind farm emissions.

Frequency: The number of sound waves or cycles passing a given point per second (measured in cycles per second and expressed as Hz).

G-weighted decibels: Noise levels adjusted so as to give greater weight to low-frequency sounds than A-weighted decibels do and used to quantify sound with a significant portion of energy in the infrasonic range below 20 Hz (expressed as dBG).

Grey literature: Multiple document types and literature produced by government, academia, business and other organisations in electronic or print format. Grey literature is not always peer-reviewed and is not controlled by commercial publishing.

Health outcome: A defined disease, state of health or health-related event that has been measured in a study.

Hertz: A measure of frequency (one cycle per second = 1 Hz).

Infrasound: A term used to describe sound in the frequency range lower than 20 Hz.

Low-frequency sound: Sound that falls within the frequency range of 20 Hz to 200–250 Hz.

Masking:* Procedures intended to keep participants in a study from knowing some facts or observations that might bias or influence their actions or decisions regarding the study (also called "blinding").

Mechanical sound: For wind turbines, the sound produced by the interaction of electrical and rotational parts such as the gearbox and generator.

Narrative review: A literature review that is conducted without a predefined protocol or method.

Noise: Unwanted sound or combination of sounds.

Participants: People who have taken part in a trial or study or have responded to a survey questionnaire or interview.

Peer-reviewed literature: Published literature that before it was published, was reviewed critically by other people in the same field of research and revised in response to the critical review as a condition of publication.

Prevalence:* A measure of occurrence or disease frequency that refers to the proportion of individuals in a population who have a disease or condition.

Psychology: The scientific study of mental functions and behaviour.

Quality of life: A person's perception of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns.

Selection bias:* Distortions in outcomes that result from the procedures used to select participants and from factors that influence participation in a study.

Self-report: Information on a person's history or personal characteristic that a person themself provides, generally from memory.

Shadow flicker: The flickering effect caused when rotating wind turbine blades intermittently cast shadows over neighbouring objects and terrain as they turn.

* Adapted from the International Epidemiological Association *Dictionary of epidemiology*.[78]

Socioeconomic status:* A descriptive term for a person's position in society, which may be expressed on an ordinal scale using such criteria as income, level of education attained, occupation, value of dwelling place etc.

Sound pressure: The local pressure deviation from the ambient (average or equilibrium) atmospheric pressure caused by a sound wave. Sound pressure can be measured in air using a microphone and in water using a hydrophone. The International System unit for sound pressure is the pascal (expressed as Pa).

Sound pressure level (or sound level): A logarithmic measure of the sound pressure of a sound relative to a reference value. It is measured in dB above a standard reference level. The standard reference sound pressure in air or other gases is 20 micropascals, which is usually considered the threshold of human hearing (at 1 kHz).

Sound: An energy form that travels from a source in the form of waves or pressure fluctuations, transmitted through a medium (e.g. air, water) and may be received by a receiver (e.g. human ear).

Supporting evidence: Includes evidence obtained from related fields that support the association between an exposure of interest and an adverse health effect (parallel evidence) and evidence for a mechanism by which an exposure of interest may cause a particular health outcome of interest (mechanistic evidence) — the mechanism may be biological, chemical or mechanical.

Systematic literature review: A process that provides a transparent and reproducible means for gathering, synthesising and appraising the findings of studies on a particular topic or question. The aim is to minimise the bias associated with the findings of single studies or non-systematic reviews.

Tinnitus: The perception of sound within the human ear (ringing in the ears) when no actual sound is present.

Tonality: # Noise containing a prominent frequency and characterised by a definite pitch.

Wind farm: A collection of wind turbines.

Wind turbine: A device that uses kinetic energy from the wind to produce electricity.

* Adapted from the International Epidemiological Association *Dictionary of epidemiology*.[78]

Definition from NSW industrial noise policy.[53]

List of acronyms and abbreviations

dB	decibels
dBA	A-weighted decibels
dBG	G-weighted decibels
Hz	Hertz
km	Kilometre
m	Metre
NHMRC	National Health and Medical Research Council
WHOQOL	World Health Organization Quality of Life scale
WHO	World Health Organization

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Wind Turbines and Health

A Critical Review of the Scientific Literature

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Objective: This review examines the literature related to health effects of wind turbines. **Methods:** We reviewed literature related to sound measurements near turbines, epidemiological and experimental studies, and factors associated with annoyance. **Results:** (1) Infrasound sound near wind turbines does not exceed audibility thresholds. (2) Epidemiological studies have shown associations between living near wind turbines and annoyance. (3) Infrasound and low-frequency sound do not present unique health risks. (4) Annoyance seems more strongly related to individual characteristics than noise from turbines. **Discussion:** Further areas of inquiry include enhanced noise characterization, analysis of predicted noise values contrasted with measured levels postinstallation, longitudinal assessments of health pre- and postinstallation, experimental studies in which subjects are "blinded" to the presence or absence of infrasound, and enhanced measurement techniques to evaluate annoyance.

The development of renewable energy, including wind, solar, and biomass, has been accompanied by attention to potential environmental health risks. Some people who live in proximity of wind turbines have raised health-related concerns about noise from their operations. The issue of wind turbines and human health has also now been explored and considered in a number of policy, regulatory, and legal proceedings.

This review is intended to assess the peer-reviewed literature regarding evaluations of potential health effects among people living in the vicinity of wind turbines. It will include analysis and commentary of the scientific evidence regarding potential links to health effects, such as stress, annoyance, and sleep disturbance, among others, that have been raised in association with living in proximity to wind turbines. Efforts will also be directed to specific components of noise associated with wind turbines such as infrasound and low-frequency sound and their potential health effects.

We will attempt to address the following questions regarding wind turbines and health:

1. Is there sufficient scientific evidence to conclude that wind turbines adversely affect human health? If so, what are the circumstances associated with such effects and how might they be prevented?
2. Is there sufficient scientific evidence to conclude that psychological stress, annoyance, and sleep disturbance can occur as a result of living in proximity to wind turbines? Do these effects lead to adverse health effects? If so, what are the circumstances associated with such effects and how might they be prevented?
3. Is there evidence to suggest that specific aspects of wind turbine sound such as infrasound and low-frequency sound have unique potential health effects not associated with other sources of environmental noise?

The coauthors represent professional experience and training in occupational and environmental medicine, acoustics, epidemiology, otolaryngology, psychology, and public health.

Earlier reviews of wind turbines and potential health implications have been published in the peer-reviewed literature[1–6] by state and provincial governments (Massachusetts, 2012, and Australia, 2014, among others) and trade associations.[7]

This review is divided into the following five sections:

1. Noise: The type associated with wind turbine operations, how it is measured, and noise measurements associated with wind turbines.
2. Epidemiological studies of populations living in the vicinity of wind turbines.
3. Potential otolaryngology implications of exposure to wind turbine sound.
4. Potential psychological issues associated with responses to wind turbine operations and a discussion of the health implications of continuous annoyance.
5. Governmental and nongovernmental reports that have addressed wind turbine operations.

METHODS

To identify published research related to wind turbines and health, the following activities were undertaken:

1. We attempted to identify and assess peer-reviewed literature related to wind turbines and health by conducting a review of PubMed, the National Library of Medicines' database that indexes more than 5500 peer-reviewed health and scientific journals with more than 21 million citations. Search terms were wind turbines, wind turbines and health effects, infrasound, infrasound and health effects, low-frequency sound, wind turbine syndrome, wind turbines and annoyance, and wind turbines and sleep disturbances.
2. We conducted a Google search for nongovernmental organization and government agency reports related to wind turbines and environmental noise exposure (see Supplemental Digital Content Appendix 1, available at: http://links.lww.com/JOM/A179).

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The authors declare no conflicts of interest.

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3. After identifying articles obtained via these searches, they were categorized into five main areas that are noted below (section D) and referred to the respective authors of each section for their review and analysis. Each author then conducted their own additional review, including a survey of pertinent references cited in the identified articles. Articles were selected for review and commentary if they addressed exposure and a health effect—whether epidemiological or experimental—or were primary exposure assessments.
4. Identified studies were categorized into the following areas:

   I. Sound, its components, and field measurements conducted in the vicinity of wind turbines;
   II. Epidemiology;
   III. Effects of sound components such as infrasound and low-frequency sound on health;
   IV. Psychological factors associated with responses to wind turbines;
   V. Governmental and nongovernmental reports.

5. The authors are aware of reports and commentaries that are not in the scientific or medical peer-reviewed literature that have raised concern about potential health implications for people who live near wind turbines. These reports describe relatively common symptoms with numerous causes, including headache, tinnitus, and sleep disturbance. Because of the difficulties in comprehensively identifying non–peer-reviewed reports such as these, and the inherent uncertainty in the quality of non–peer-reviewed reports, they were not included in our analysis, aside from some books and government reports that are readily identified. A similar approach of excluding non–peer-reviewed literature in scientific reviews is used by the World Health Organization (WHO)'s International Agency for Research on Cancer (IARC) in its deliberations regarding identification of human carcinogens.[8] International Agency for Research on Cancer, however, critically evaluates exposure assessments not published in the peer-reviewed literature, if conducted with appropriate quality and in accordance with international standards and guidelines. International Agency for Research on Cancer uses this policy for exposure assessments because many of these efforts, although containing valuable data in evaluating health risks associated with an exposure to a hazard, are not routinely published. The USA National Toxicology Program also limits its critical analysis of potential carcinogens to the peer-reviewed literature. In our view, because of the critical effect of scientific studies on public policy, it is imperative that peer-reviewed literature be used as the basis. Thus, in this review, only peer review studies are considered, aside from exposure-related assessments.

RESULTS

Characteristics of Wind Turbine Sound

In this portion of the review, we evaluate studies in which sound near wind turbines has been measured, discuss the use of modeled sound levels in dose–response studies, and review literature on measurements of low-frequency sound and infrasound from operating wind turbines. We evaluate sound levels measured in areas, where symptoms have been reported in the context of proximity to wind turbines. We address methodologies used to measure wind turbine noise and low-frequency sound. We also address characteristics of wind turbine sound, sound levels measured near existing wind turbines, and the response of humans to different levels and characteristics of wind turbine sound. Special attention is given to challenges and methods of measuring wind turbine noise, as well as low-frequency sound (20 to 200 Hz) and Infrasound (less than 20 Hz).

Wind turbines sound is made up from both moving components and interactions with nonmoving components of the wind turbine (Fig. 1). For example, mechanical components in the nacelle can generate noise and vibration, which can be radiated from the structure, including the tower. The blade has several components that create aerodynamic noise, such as the blade leading edge, which contacts the wind first in its rotation, the trailing edge, and the blade tip. Blade/tower interactions, especially where the blades are downwind of the tower, can create infrasound and low-frequency sound. This tower orientation is no longer used in large wind turbines.[9]

Sound Level and Frequency

Sound is primarily characterized by its pitch or frequency as measured in Hertz (Hz) and its level as measured in decibels (dB). The frequency of a sound is the number of times in a second that the medium through which the sound energy is traveling (ie, air, in the case of wind turbine sound) goes through a compression cycle. Normal human hearing is generally in the range of 20 to 20,000 Hz. As an example, an 88-key piano ranges from about 27.5 to 4186 Hz with middle C at 261.6 Hz. As in music, ranges of frequencies can be described in "octaves," where the center of each octave band has a frequency of twice that of the previous octave band (this is also written as a "1/1 octave band"). Smaller subdivisions can be used such as 1/3 and 1/12 octaves. The level of sound pressure for each frequency band is reported in decibel units.

To represent the overall sound level in a single value, the levels from each frequency band are logarithmically added. Because human hearing is relatively insensitive to very low- and high-frequency sounds, frequency-specific adjustments or weightings are added to the unweighted sound levels before summing to the overall level. The most common of these is the A-weighting, which simulates the human response to various frequencies at relatively low levels (40 phon or about 50 dB). Examples of A-weighted sound levels are shown in Fig. 2.

Other weightings are cited in the literature, such as the C-weighting, which is relatively flat at the audible spectrum; G-weighting, which simulates human perception and annoyance of sound that lie wholly or partly in the range from 1 to 20 Hz; and Z-weighting, which does not apply any weighting. The weighting of the sound is indicated after the dB label. For example, an A-weighted sound level of 45 dB would be written as 45 dBA or 45 dB(A). If no label is shown, the weighting is either implied or unweighted.

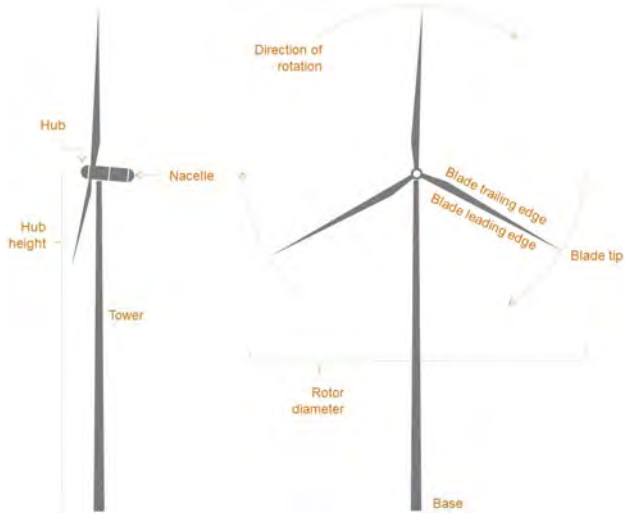

FIGURE 1 . Schematic of a modern day wind turbine.

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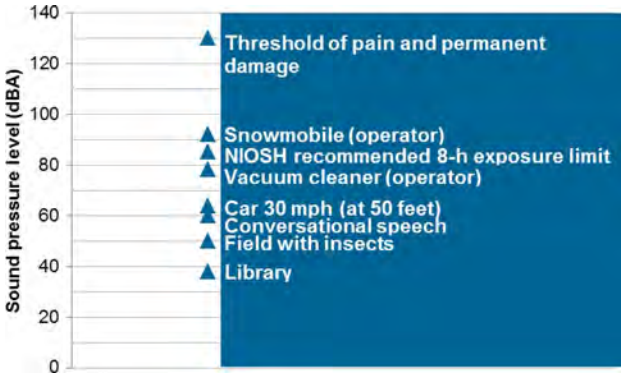

FIGURE 2. Sample A-weighted sound pressure levels.

Beyond the overall level, wind turbine noise may be amplitude modulated or have tonal components. Amplitude modulation is a regular cycling in the level of pure tone or broadband sound. A typical three-bladed wind turbine operating at 15 RPM would have a modulation period or cycle length of about 1.3 seconds. Tones are frequencies or narrow frequency bands that are much louder than the adjacent frequencies in sound spectra. Prominent tones can be identified through several standards, including ANSI S12.9 Part 4 and IEC 61400-11. Relative high-, mid-, and low-frequency content can also define how the sound is perceived, as well as many qualitative factors unique to the listener. Consequently, more than just the overall levels can be quantified, and studies have measured the existence of amplitude modulation, prominent tones, and spectral content in addition to the overall levels.

Wind Turbine Sound Power and Pressure Levels

The sound *power* level is the intrinsic sound energy radiated by a source. It is not dependent on the particular environment of the sound source and the location of the receiver relative to the source. The sound *pressure* level (SPL), which is measured by a sound-level meter at a location, is a function of the sound *power* emitted by neighboring sources and is highly dependent on the environment and the location of the receiver relative to the sound source(s).

Wind turbine sound is typically broadband in character with most of the sound energy at lower frequencies (less than 1000 Hz). Although wind turbines produce sound at frequencies less than the 25 Hz 1/3 octave band, sound power data are rarely published below that frequency. Most larger, utility-scale wind turbines have sound power levels between 104 and 107 dBA. Measured sound levels because of wind turbines depend on several factors, including weather conditions, the number of turbines, turbine layout, local topography, the particular turbine used, distance between the turbines and the receiver, and local flora. Meteorological conditions alone can cause 7 to 14 dB variations in sound levels.[10] Examples of the SPLs because of a single wind turbine with three different sound powers, and at various distances, are shown in Fig. 3 as calculated with ISO 9613-2.[11] Measurement results of A-weighted, C-weighted, and G-weighted sound levels have confirmed that wind turbine sound attenuates logarithmically with respect to distance.[12]

With respect to noise standards, Hessler and Hessler[13] found an arithmetic average of 45 dBA daytime and 40 dBA nighttime for governments outside the United States, and a nighttime average of 47.7 dBA for US state noise regulation and siting standards. The metrics for those levels can vary. Common metrics are the day-evening-night level (Lden), day-night level (Ldn), equivalent average level (Leq), level exceeded 90% of the time (L90), and median (L50). The application of how these are measured and the time period over which they are measured varies, meaning that, from a practical

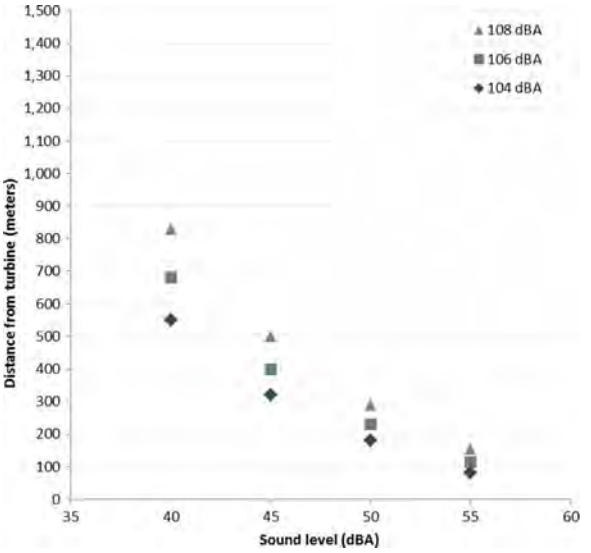

FIGURE 3. Sound levels at varying setbacks and turbine sound power levels—RSG Modeling, Using ISO 9613-2.

standpoint, sound-level limits are even more varied than the explicit numerical level. The Leq is one of the more commonly used metric. It is the logarithmic average of the squared relative pressure over a period of time. This results in a higher weighting of louder sounds.

Owing to large number of variables that contribute to SPLs because of wind turbines at receivers, measured levels can vary dramatically. At a wind farm in Texas, O'Neal et al[14] measured sound levels with the nearest turbine at 305 m (1000 feet) and with four turbines within 610 m (2000 feet) at 50 to 51 dBA and 63 dBC (10-minute Leq), with the turbines producing sufficient power to emit the maximum sound power. During the same test, sound levels were 27 dBA and 47 dBC (10-minute Leq) inside a home that was located 290 m (950 feet) from the nearest turbine and within 610 m (2000 feet) of four turbines[15] (see Fig. 4).

Bullmore et al[16] measured wind turbine sound at distances from 100 to 754 m (330 to 2470 feet), where they found sound levels ranging from 40 to 55 dBA over various wind conditions. At typical receiver distances (greater than 300 m or 1000 feet), sound was attenuated to below the threshold of hearing at frequencies above the 1.25 kHz 1/3 octave band. In studies mentioned here, measurements were made with the microphone between 1 and 1.6 m (3 and 5 feet) above ground.

Wind Turbine Emission Characteristics

Low-Frequency Sound and Infrasound

Low-frequency sound is typically defined as sound from 20 to 200 Hz, and infrasound is sound less than 20 Hz. Low-frequency sound and infrasound measurement results at distances close to wind turbines (< 500 meters) typically show infrasound because of wind farms, but not above audibility thresholds (such as ISO 226 or as published by the authors[12,15,17–21,149]). One study found sound levels 360 m and 200 m from a wind farm to be 61 dBG and 63 dBG, respectively. The threshold of audibility for G-weighted sound levels is 85 dBG. The same paper found infrasound levels of 69 dBG 250 m from a coastal cliff face and 76 dBG in downtown Adelaide, Australia.[18] One study found that, even at distances less than 450 feet (136 m), infrasound levels were 80 dBG or less. At more typical receiver distances (greater than 300 m or 1000 feet), infrasound levels were 72 dBG or less. This corresponded to A-weighted sound

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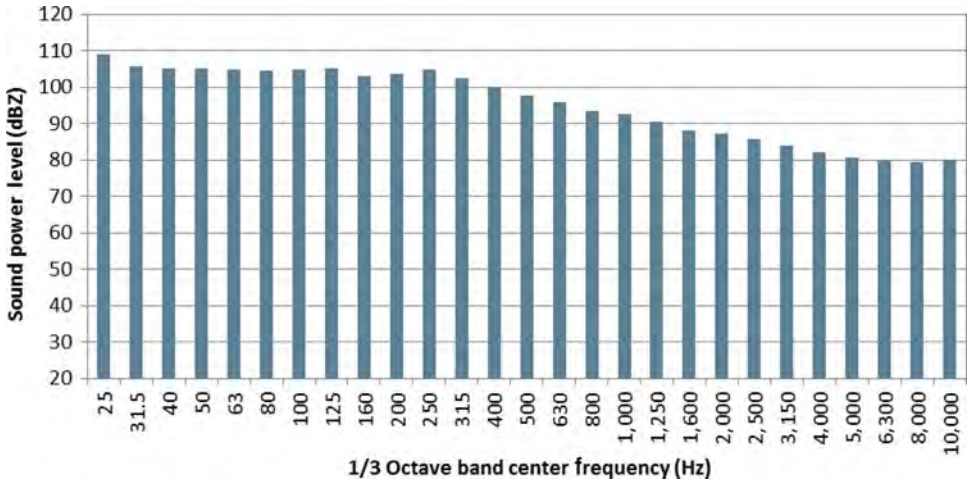

FIGURE 4. Sound power of the Siemens SWT 2.3-93 (TX) wind turbine.[15]

levels of 56 and 49 dBA, respectively, higher than most existing regulatory noise limits.[12]

Farther away from wind farms (1.5 km) infrasound is no higher than what would be caused by localized wind conditions, reinforcing the necessity for adequate wind-caused pseudosound reduction measures for wind turbine sound-level measurements.[22]

Low-frequency sound near wind farms is typically audible, with levels crossing the threshold of audibility between 25 and 125 Hz depending on the distance between the turbines and measurement location.[12,15,19,20,23] Figure 5 shows the frequency spectrum of a wind farm measured at about 3500 feet compared with a truck at 50 feet, a field of insects and birds, wind moving through vegetation, and the threshold of audibility according to ISO 387-7.

Amplitude Modulation

Wind turbine sound emissions vary with blade velocity and are characterized in part by amplitude modulation, a broadband oscillation in sound level, with a cycle time generally corresponding to the blade passage frequency. The modulation is typically located in the 1/1 octave bands from 125 Hz to 2 kHz. Fluctuation magnitudes are typically not uniform throughout the frequency range. These fluctuations are typically small (2 to 4 dB) but under more unusual circumstances can be as great as 10 dB for A-weighted levels and as much as 15 dB in individual 1/3 octave bands.[19,24] Stigwood et al[24] found that, in groups of several turbines, the individual modulations can often synchronize causing periodic increases in the modulation magnitude for periods of 6 to 20 seconds with occasional periods where the individual turbine modulations average each other out, minimizing the modulation magnitude. This was not always the case though, with periods of turbine synchronization occasionally lasting for hours under consistent high wind shear, wind strength, and wind direction.

Amplitude modulation is caused by many factors, including blade passage in front of the tower (shadowing), sound emission directivity of the moving blade tips, yaw error of the turbine blades (where the turbine blades are not perpendicular to the wind), inflow turbulence, and high levels of wind shear.[19,24,25] Amplitude modulation level is not correlated with wind speed. Most occurrences of "enhanced" amplitude modulation (a higher magnitude of modulation) are caused by anomalous meteorological conditions.[19] Amplitude modulation varies by site. Some sites rarely exhibit amplitude modulation, whereas at others amplitude modulation has been measured up to 30% of the time.[10] It has been suggested by some that amplitude modulation may be the cause of "infrasound" complaints because of confusing of amplitude modulation, the modulation of a broadband sound, with actual infrasound.[19]

Tonality

Tones are specific frequencies or narrow bands of frequencies that are significantly louder than adjacent frequencies. Tonal sound is not typically generated by wind turbines but can be found in some cases.[20,26] In most cases, the tonal sound occurs at lower frequencies (less than 200 Hz) and is due to mechanical noise originating from the nacelle, but has also been found to be due to structural vibrations originating from the tower, and anomalous aerodynamic characteristics of the blades[27] (see Fig. 5).

Sound Levels at Residences where Symptoms Have Been Reported

One recent research focus has been the sound levels at (and in) the residences of people who have complained about sound levels emitted by turbines as some have suggested that wind turbine noise may be a different type of environmental noise.[28] Few studies have actually measured sound levels inside or outside the homes of people. Several hypotheses have been proposed about the characteristics of wind turbine noise complaints, including infrasound,[28] low-frequency tones,[20] amplitude modulation,[19,29] and overall noise levels.

Overall Noise Levels

Because of the large variability of noise sensitivity among people, sound levels associated with self-reported annoyance can vary considerably. (Noise sensitivity and annoyance are discussed in more detail later in this review.) People exposed to measured external sound levels from 38 to 53 dBA (10-minute or 1-hour Leq). Department of Trade and Industry,[19] Walker et al,[28] Gabriel et al,[29] and van den Berg et al[30,149] have reported annoyance. Sound levels have also been measured inside complainant residences at between 22 and 37 dBA (10-minute Leq).[19]

Low Frequency and Infrasonic Levels

Concerns have been raised in some settings that low-frequency sound and infrasound may be special features of wind turbine noise that lead to adverse health effects.[31] As a result, noise measurements in areas of operating wind turbines have focused specifically

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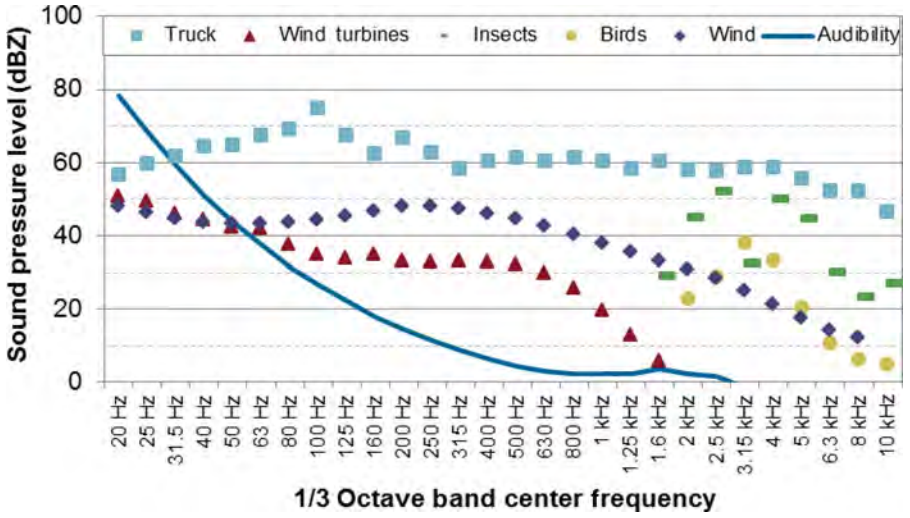

FIGURE 5. Comparison of frequency spectrum of a truck passby at 50 feet, wind turbines at 3500 feet, insects, birds, wind, and the threshold of audibility according to ISO 387-7.

on sound levels in the low-frequency range and occasionally the infrasonic range.

Infrasonic sound levels at residences are typically well below published audibility thresholds, even thresholds for those particularly sensitive to infrasound. Nevertheless, low-frequency sound typically exceeds audibility thresholds in a range starting between 25 and 125 Hz.[19,20,23] In some cases, harmonics of the blade passage frequency (about 1 Hz, ie infrasound) have been measured at homes of people who have raised concerns about health implications of living near wind turbine with sound levels reaching 76 dB; however, these are well below published audibility thresholds.[28]

Amplitude Modulation

Amplitude modulation has been suggested as a major cause of complaints surrounding wind turbines, although little data have been collected to confirm this hypothesis. A recent study of residents surrounding a wind farm that had received several complaints showed predicted sound levels at receiver distances to be 33 dBA or less. Residents were instructed to describe the turbine sound, when they found it annoying. Amplitude modulation was present in 68 of 95 complaints. Sound recorders distributed to the residents exhibited a high incidence of amplitude modulation.[29]

Limited studies have addressed the percentage of complaints surrounding utility-scale wind farms, with only one comparing the occurrence of complaints with sound levels at the homes. The complaint rate among residents within 2000 feet (610 m) of the perimeter of five mid-western United States wind farms was approximately 4%. All except one of the complaints were made at residences, where wind farm sound levels exceeded 40 dBA.[13] The authors used the LA90 metric to assess wind farm sound emissions. LA90 is the A-weighted sound level that is exceeded 90% of the time. This metric is used to eliminate wind-caused spikes and other short-term sound events that are not caused by the wind farm.

In Northern New England, 5% of households within 1000 m of turbines complained to regulatory agencies about wind turbine noise.[32] All complaints were included, even those that were related to temporary issues that were resolved. Up to 48% of the complainants were at wind farms, where at least one noise violation was found or a variance from the noise standard. A third of the all complaints were due to a single wind farm.

Sound Measurement Methodology

Collection of accurate, comparable, and useful noise data depends on careful and consistent methodology. The general methodology for environmental sound level monitoring is found in ANSI 12.9 Part 2. This standard covers basic requirements that include the type of measurement equipment necessary, calibration procedures, windscreen specifications, microphone placement guidance, and suitable meteorological conditions. Nevertheless, there are no recommendations for mitigating the effects of *high* winds (greater than 5 m/s) or measuring in the infrasonic frequency range (less than 20 Hz).[33] Another applicable standard is IEC 61400-11, which provides a method for determining the sound power of individual wind turbines. The standard gives specifications for measurement positions, the type of data needed, data analysis methods, report content requirements, determination of tonality, determination of directivity, and the definitions and descriptors of different acoustical parameters.[34] The standard specifies a microphone mounting method to minimize wind-caused pseudosound, but some have found the setup to be insufficient under gusty wind conditions, and no recommendations are given for infrasound measurement.[35] Because the microphone is ground mounted, it is not suitable for long-term measurements.

Low-Frequency Sound and Infrasound Measurement

There are no standards currently in place for the measurement of wind turbine noise that includes the infrasonic range (ie, frequencies less than 20 Hz), although one is under development (ANSI/ASA S12.9 Part 7). Consequently, all current attempts to measure low-frequency sound and infrasound have either used an existing methodology, an adapted existing methodology, or proposed a new methodology.

The main problem with measuring low-frequency sound and infrasound in environmental conditions is wind-caused pseudosound due to air pressure fluctuation, because air flows over the microphone. With conventional sound-level monitoring, this effect is minimized with a wind screen and/or elimination of data measured during windy periods (less than 5 m/s [11 mph] at a 2-m [6.5 feet] height).[36] In the case of wind turbines, where maximum sound levels may be coincident with ground wind speeds greater than 5 m/s (11 mph), this is not the best solution. With infrasound in particular, wind-caused pseudosound can influence measurements, even at wind speeds down to 1 m/s.[12] In fact, many sound-level meters do not measure infrasonic frequencies.

A common method of dealing with infrasound is using an additional wind screen to further insulate the microphone from air flow.[18,35] In some cases, this is simply a larger windscreen that further insulates the microphone from air flow.[35] One author used a

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windscreen with a subterranean pit to shelter the microphone, and another used wind resistant cloth.[35] A compromise to an underground microphone mounting is mounting the microphone close (20-cm height) to the ground, minimizing wind influence, or using a standard ground mounted microphone with mounting plate, as found in IEC 61400-11.[35] Low-frequency sound and infrasound differences between measurements made with dedicated specialized windscreens and/or measurement setup and standard wind screens/measurements setups can be quite large.[12,37] Nevertheless, increased measurement accuracy can come at the cost of reduced accuracy at higher frequencies using some methods.[38]

To further filter out wind-caused pseudosound, some authors have advocated a combination of microphone arrays and signal processing techniques. The purpose of the signal processing techniques is to detect elements of similarity in the sound field measured at the different microphones in the array.

Levels of infrasound from other environmental sources can be as high as infrasound from wind turbines. A study of infrasound measured at wind turbines and at other locations away from wind turbines in South Australia found that the infrasound level at houses near the wind turbines is no greater than that found in other urban and rural environments. The contribution of wind turbines to the infrasound levels is insignificant in comparison with the background level of infrasound in the environment.[22]

Conclusions

Wind turbine noise measurement can be challenging because of the necessity of measuring sound levels during high winds, and down to low frequencies. No widely accepted measurement methodologies address all of these issues, meaning that methods used in published measurements can differ substantially, affecting the comparability of results.

Measurements of low-frequency sound, infrasound, tonal sound emission, and amplitude-modulated sound show that infrasound is emitted by wind turbines, but the levels at customary distances to homes are typically well below audibility thresholds, even at residences where complaints have been raised. Low-frequency sound, often audible in wind turbine sound, typically crosses the audibility threshold between 25 and 125 Hz depending on the location and meteorological conditions.[12,15,19,20,23] Amplitude modulation, or the rapid (once per second) and repetitive increase and decrease of broadband sound level, has been measured at wind farms. Amplitude modulation is typically 2 to 4 dB but can vary more than 6 dB in some cases (A-weighted sound levels).[19,24]

A Canadian report investigated the total number of noise-related complaints because of operating wind farms in Alberta, Canada, over its entire history of wind power. Wind power capacity exceeds 1100 MW; some of the turbines have been in operation for 20 years. Five noise-oriented complaints at utility-scale wind farms were reported over this period, none of which were repeated after the complaints were addressed. Complaints were more common during construction of the wind farms; other power generation methods (gas, oil, etc) received more complaints than wind power. Farmers and ranchers did not raise complaints because of effects on crops and cattle.[41] An Australian study found a complaint rate of less than 1% for residents living within 5 km of turbines greater than 1 MW. Complaints were concentrated among a few wind farms; many wind farms never received complaints.[15]

Reviewing complaints in the vicinity of wind farms can be effective in determining the level and extent of annoyance because of wind turbine noise, but there are limitations to this approach. A complaint may be because of higher levels of annoyance (rather annoyed or very annoyed), and the amount of annoyance required for an individual to complain may be dependent on the personality of the person and the corresponding attitude toward the visual effect of the turbines, their respective attitudes toward wind energy, and whether they derive economic benefit from the turbines. (All of these factors are discussed in more detail later in this report.)

Few studies have addressed sound levels at the residents of people who have described symptoms they consider because of wind turbines. Limited available data show a wide range of levels (38 to 53 dBA [10-minute or 1-hour Leq] outside the residence and from 23 to 37 dBA [10-minute Leq] inside the residence).[19,26,28,28] The rate of complaints surrounding wind farms is relatively low; 3% for residents within 1 mile of wind farms and 4% to 5% within 1 km.[13,32,41]

Epidemiological Studies of Wind Turbines

Key to understanding potential effects of wind turbine noise on human health is to consider relevant evidence from well-conducted epidemiological studies, which has the advantage of reflecting risks of real-world exposures. Nevertheless, environmental epidemiology is an observational (vs experimental) science that depends on design and implementation characteristics that are subject to numerous inherent and methodological limitations. Nevertheless, evidence from epidemiological studies of reasonable quality may provide the best available indication of whether certain exposures—such as industrial wind turbine noise—may be harming human health. Critical review and synthesis of the epidemiological evidence, combined with consideration of evidence from other lines of inquiry (ie, animal studies and exposure assessments), provide a scientific basis for identifying causal relationships, managing risks, and protecting public health.

Methods

Studies of greatest value for validly identifying risk factors for disease include well-designed and conducted cohort studies and case–control studies—provided that specific diseases could be identified—followed by cross-sectional studies (or surveys). Case reports and case series do not constitute epidemiological studies and were not considered because they lack an appropriate comparison group, which can obscure a relationship or even suggest one where none exists.[39,40,42] Such studies may be useful in generating hypotheses that might be tested using epidemiological methods but are not considered capable of demonstrating causality, a position also taken by international agencies such as the WHO.[8]

Epidemiological studies selected for this review were identified through searches of PubMed and Google Scholar using the following key words individually and in various combinations: "wind," "wind turbine," "wind farm," "windmill," "noise," "sleep," "cardiovascular," "health," "symptom," "condition," "disease," "cohort," "case–control," "cross-sectional," and "epidemiology." In addition, general Web searches were performed, and references cited in all identified publications were reviewed. Approximately 65 documents were identified and obtained, and screened to determine whether (1) the paper described a primary epidemiological study (including experimental or laboratory-based study) published in a peer-reviewed health, medical or relevant scientific journal; (2) the study focused on or at least included wind turbine noise as a risk factor; (3) the study measured at least one outcome of potential relevance to health; and (4) the study attempted to relate the wind turbine noise with the outcome.

Results

Of the approximately 80 articles initially identified in the search, only 20 met the screening criteria (14 observational and six controlled human exposure studies), and these were reviewed in detail to determine the relative quality and validity of reported findings. Other documents included several reviews and commentaries[4,5,7,43–51]; case reports, case studies, and surveys[23,52–54]; and documents published in media other than peer-reviewed journals. One study published as part of a conference

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proceedings did not meet the peer-reviewed journal eligibility criterion but was included because it seemed to be the first epidemiological study on this topic and an impetus for subsequent studies.[55]

The 14 observational epidemiological studies were critically reviewed to assess their relative strengths and weaknesses on the basis of the study design and the general ability to avoid selection bias (eg, the selective volunteering of individuals with health complaints), information bias (eg, under- or overreporting of health complaints, possibly because of reliance on self-reporting), and confounding bias (the mixing of possible effects of other strong risk factors for the same disease because of correlation with the exposure).

Figure 6 depicts the 14 observational epidemiological studies published in peer-reviewed health or medical journals, all of which were determined to be cross-sectional studies or surveys. As can be seen from the figure, the 14 publications were based on analyses of data from only eight different study populations, that is, six publications were based on analyses of a previously published study (eg, Pedersen et al[56] and Bakker et al[57] were based on the data from Pedersen et al[58]) or on combined data from previously published studies (eg, Pedersen and Larsman[59] and Pedersen and Waye[60] were based on the combined data from Pedersen and Waye[61,62]; and Pedersen[63] and Janssen et al[64] were based on the combined data from Pedersen et al,[58] Pedersen and Waye,[61] and Pedersen and Waye[62]). Therefore, in the short summaries of individual studies below, publications based on the same study population(s) are grouped.

Summary of Observational Epidemiological Studies

Possibly the first epidemiological study evaluating wind turbine sound and noise annoyance was published in the proceedings of the 1993 European Community Wind Energy Conference.[55] Investigators surveyed 574 individuals (159 from the Netherlands, 216 from Germany, and 199 from Denmark). Up to 70% of the people

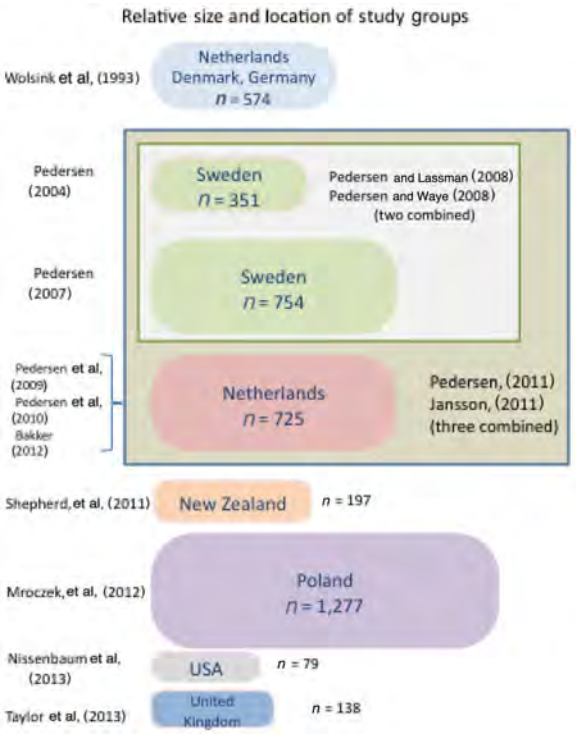

FIGURE 6. The 14 observational epidemiological studies published in peer-reviewed health or medical journals, all of which were determined to be cross-sectional studies or surveys.

resided near wind turbines for at least 5 years. No response rates were reported, so the potential for selection or participation bias cannot be evaluated. Wind turbine sound levels were calculated in 5 dBA intervals for each respondent, on the basis of site measurements and residential distance from turbines. The authors claimed that noise-related annoyance was weakly correlated with objective sound levels but more strongly correlated with indicators of respondents' attitudes and personality.[55]

In a cross-sectional study of 351 participants residing in proximity to wind turbines (power range 150 to 650 kW), Pederson (a coauthor of the Wolsink[55] study) and Persson and Waye[61] described a statistically significant association between modeled wind turbine audible noise estimates and self-reported annoyance. In this section, "statistically significant" means that the likelihood that the results were because of chance is less than 5%. No respondents among the 12 exposed to wind turbine noise less than 30 dBA reported annoyance with the sound; however, the percentage reporting annoyance increased with noise exceeding 30 dBA. No differences in health or well-being outcomes (eg, tinnitus, cardiovascular disease, headaches, and irritability) were observed. With noise exposures greater than 35 dBA, 16% of respondents reported sleep disturbance, whereas no sleep disturbance was reported among those exposed to less than 35 dBA. Although the authors observed that the risk of annoyance from wind turbine noise exposure increased statistically significantly with each increase of 2.5 dBA, they also reported a statistically significant risk of reporting noise annoyance among those self-reporting a negative attitude toward the visual effect of the wind turbines on the landscape scenery (measured on a five-point scale ranging from "very positive" to "very negative" opinion). These results suggest that attitude toward visual effect is an important contributor to annoyance associated with wind turbine noise. In addition to its reliance on self-reported outcomes, this study is limited by selection or participation bias, suggested by the difference in response rate between the highest-exposed individuals (78%) versus lowest-exposed individuals (60%).

Pederson[62] examined the association between modeled wind turbine sound pressures and self-reported annoyance, health, and well-being among 754 respondents in seven areas in Sweden with wind turbines and varying landscapes. A total of 1309 surveys were distributed, resulting in a response rate of 57.6%. Annoyance was significantly associated with SPLs from wind turbines as well as having a negative attitude toward wind turbines, living in a rural area, wind turbine visibility, and living in an area with rocky or hilly terrain. Those annoyed by wind turbine noise reported a higher prevalence of lowered sleep quality and negative emotions than those not annoyed by noise. Because of the cross-sectional design, it cannot be determined whether wind turbine noise caused these complaints or if those who experienced disrupted sleep and negative emotions were more likely to notice and report annoyance from noise. Measured SPLs were not associated with any health effects studied. In the same year, Petersen et al reported on what they called a "grounded theory study" in which 15 informants were interviewed in depth regarding the reasons they were annoyed with wind turbines and associated noise. Responses indicated that these individuals perceived the turbines to be an intrusion and associated with feelings of lack of control and influence.[65] Although not an epidemiological study, this exercise was intended to elucidate the reasons underlying the reported annoyance with wind turbines.

Further analyses of the combined data from Pedersen and Waye[61,62] (described above) were published in two additional papers.[59,60] The pooled data included 1095 participants exposed to wind turbine noise of at least 30 dBA. As seen in the two original studies, a significant association between noise annoyance and SPL was observed. A total of 84 participants (7.7%) reported being fairly or very annoyed by wind turbine noise. Respondents reporting wind turbines as having a negative effect on the scenery were also

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statistically significantly more likely to report annoyance to wind turbine noise, regardless of SPLs.[59] Self-reported stress was higher among those who were fairly or very annoyed compared with those not annoyed; however, these associations could not be attributed specifically to wind turbine noise. No differences in self-reported health effects such as hearing impairment, diabetes, or cardiovascular diseases were reported between the 84 (7.7%) respondents who were fairly or very annoyed by wind turbine noise compared with all other respondents.[60] The authors did not report the power of the study.

Pederson et al[56–58] evaluated the data from 725 residents in the Netherlands living within 2.5 km of a site containing at least two wind turbines of 500 kW or greater. Using geographic information systems methods, 3727 addresses were identified in the study target area, for which names and telephone numbers were found for 2056; after excluding businesses, 1948 were determined to be residences and contacted. Completed surveys were received from 725 for a response rate of 37%. Although the response rate was lower than in previous cross-sectional studies, nonresponse analyses indicated that similar proportions responded across all landscape types and sound pressure categories.[57] Calculated sound levels, other sources of community noise, noise sensitivity, general attitude, and visual attitude toward wind turbines were evaluated. The authors reported an exposure–response relationship between calculated A-weighted SPLs and self-reported annoyance. Wind turbine noise was reported to be more annoying than transportation noise or industrial noise at comparable levels. Annoyance, however, was also correlated with a negative attitude toward the visual effect of wind turbines on the landscape. In addition, a statistically significantly decreased level of annoyance from wind turbine noise was observed among those who benefited economically from wind turbines, despite equal perception of noise and exposure to generally higher (greater than 40 dBA) sound levels.[58] Annoyance was strongly correlated with self-reporting a negative attitude toward the visual effect of wind turbines on the landscape scenery (measured on a five-point scale ranging from "very positive" to "very negative" opinion). The low response rate and reliance on self-reporting of noise annoyance limit the interpretation of these findings.

Results of further analyses of noise annoyance were reported in a separate report,[56] which indicated that road traffic noise had no effect on annoyance to wind turbine noise and vice versa. Visibility of, and attitude toward, wind turbines and road traffic were significantly related to annoyance from their respective noise source; stress was significantly associated with both types of noise.[56,157]

Additional analyses of the same data were performed using a structural equation approach that indicated that, as with annoyance, sleep disturbance increased with increasing SPL because of wind turbines; however, this increase was statistically significant only at pressures of 45 dBA and higher. Results of analyses of the combined data from the two Swedish[61,62] and the Dutch[58] cross-sectional studies have been published in two additional papers. Using the combined data from these three predecessor studies, Pedersen et al[56,58] identified 1755 (ie, 95.9%) of the 1830 total participants for which complete data were available to explore the relationships between calculated A-weighted SPLs and a range of indicators of health and well-being. Specifically, they considered sleep interruption; headache; undue tiredness; feeling tense, stressed, or irritable; diabetes; high blood pressure; cardiovascular disease; and tinnitus.[63] As in the precursor studies, noise annoyance indoors and outdoors was correlated with A-weighted SPLs. Sleep interruption seemed at higher sound levels and was also related to annoyance. No other health or well-being variables were consistently related to SPLs. Stress was not directly associated with SPLs but was associated with noise-related annoyance.

Another report based on these data (in these analyses, 1820 of the 1830 total participants) modeled the relationship between wind turbine noise exposure and annoyance indoors and outdoors.[64] The authors excluded respondents who benefited economically from wind turbines, then compared their modeled results with other modeled relationships for industrial and transportation noise; they claimed that annoyance from wind turbine noise at or higher than 45 dBA is associated with more annoyance than other noise sources.

Shepherd et al,[66] who had conducted an earlier evaluation of noise sensitivity and Health Related Quality of Life (HRQL),[158] compared survey results from 39 residents located within 2 km of a wind turbine in the South Makara Valley in New Zealand with 139 geographically and socioeconomically matched individuals who resided at least 8 km from any wind farm. The response rates for both the proximal and more distant study groups were poor, that is, 34% and 32%, respectively, although efforts were made to blind respondents to the study hypotheses. No indicator of exposure to wind turbine noise was considered beyond the selection of individuals based on the proximity of their residences from the nearest wind turbine. Health-related quality-of-life (HRQOL) scales were used to describe and compare the general well-being and well-being in the physical, psychological, and social domains of each group. The authors reported statistically significant differences between the groups in some HRQOL domain scores, with residents living within 2 km of a turbine installation reporting lower mean physical HRQOL domain score (including lower component scores for sleep quality and self-reported energy levels) and lower mean environmental quality-of-life (QOL) scores (including lower component scores for considering one's environment to be less healthy and being less satisfied with the conditions of their living space). No differences were reported for social or psychological HRQOL domain scores. The group residing closer to a wind turbine also reported lower amenity but not related to traffic or neighborhood noise annoyance. Lack of actual wind turbine and other noise source measurements, combined with the poor response rate (both noted by the authors as limitations), limits the inferential value of these results because they may pertain to wind turbine emissions.[66]

Possibly the largest cross-sectional epidemiological study of wind turbine noise on QOL was conducted in an area of northern Poland with the most wind turbines.[67] Surveys were completed by a total of 1277 adults (703 women and 574 men), aged 18 to 94 years, representing a 10% two-stage random sample of the selected communities. Although the response rate was not reported, participants were sequentially enrolled until a 10% sample was achieved, and the proportion of individuals invited to participate but unable or refusing to participate was estimated at 30% (B. Mroczek, dr hab n. zdr., e-mail communication, January 2, 2014). Proximity of residence was the exposure variable, with 220 (17.2%) respondents within 700 m; 279 (21.9%) between 700 and 1000 m; 221 (17.3%) between 1000 and 1500 m; and 424 (33.2%) residing more than 1500 m from the nearest wind turbine. Indicators of QOL and health were measured using the Short Form–36 Questionnaire (SF-36). The SF-36 consists of 36 questions specifically addressing physical functioning, role-functioning physical, bodily pain, general health, vitality, social functioning, role-functioning emotional, and mental health. An additional question concerning health change was included, as well as the Visual Analogue Scale for health assessment. It is unclear whether age, sex, education, and occupation were controlled for in the statistical analyses. The authors report that, within all subscales, those living closest to wind farms reported the best QOL, and those living farther than 1500 m scored the worst. They concluded that living in close proximity of wind farms does not result in the worsening of, and might improve, the QOL in this region.[67]

A small survey of residents of two communities in Maine with multiple industrial wind turbines compared sleep and general health outcomes among 38 participants residing 375 to 1400 m from the nearest turbine with another group of 41 individuals residing 3.3 to 6.6 km from the nearest wind turbine.[68] Participants completed questionnaires and in-person interviews on a range of

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health and attitudinal topics. Prevalence of self-reported health and other complaints was compared by distance from the wind turbines, statistically controlling for age, sex, site, and household cluster in some analyses. Participants living within 1.4 km of a wind turbines reported worse sleep, were sleepier during the day, and had worse SF-36 Mental Component Scores compared with those living farther than 3.3 km away. Statistically significant correlations were reported between Pittsburgh Sleep Quality Index, Epworth Sleepiness Scale, SF-36 Mental Component Score, and log-distance to the nearest wind turbine. The authors attributed the observed differences to the wind turbines[68]; methodological problems such as selection and reporting biases were overlooked. This study has a number of methodological limitations, most notably that all of the "near" turbine groups were plaintiffs in a lawsuit against the wind turbine operators and had already been interviewed by the lead investigator prior to the study. None of the "far" group had been interviewed; they were "cold called" by an assistant. This differential treatment of the two groups introduces a bias in the integrity of the methods and corresponding results. Details of the far group, as well as participation rates, were not noted.[68]

In another study, the role of negative personality traits (defined by the authors using separate scales for assessing neuroticism, negative affectivity, and frustration intolerance) on possible associations between actual and perceived wind turbine noise and medically unexplained nonspecific symptoms was investigated via a mailed survey.[69] Of the 1270 identified households within 500 m of eight 0.6 kW micro-turbine farms and within 1 km of four 5 kW small wind turbine farms in two cities in the United Kingdom, only 138 questionnaires were returned, for a response rate of 10%. No association was noted between calculated and actual noise levels and nonspecific symptoms. A correlation between perceived noise and nonspecific symptoms was seen among respondents with negative personality traits. Despite the participant group's reported representativeness of the target population, the low survey response rate precludes firm conclusions on the basis of these data.[69]

In a study of residents living near a "wind park" in Western New York State, surveys were administered to 62 individuals living in 52 homes.[70] The wind park included 84 turbines. No association was noted between self-reported annoyance and short duration sound measurements. A correlation was noted between the measure of a person's concern regarding health risks and reported measures of the prevalence of sleep disturbance and stress. While a cross-sectional study is based on self-reported annoyance and health indicators, and therefore limited in its interpretation, one of its strengths is that it is one of the few studies that performed actual sound measurements (indoors and outdoors).

A small but detailed study on response to the wind turbine noise was carried out in Poland.[71] The study population consisted of 156 people, age 15–82 years, living in the vicinity of 3 wind farms located in the central and northwestern parts of Poland. No exclusion criteria were applied, and each individual agreeing to participate was sent a questionnaire patterned after the one used in the Pederson 2004 and Pederson 2007 studies and including questions on living conditions, self-reported annoyance due to noise from wind turbines, and self-assessment of physical health and well-being (such as headaches, dizziness, fatigue, insomnia, and tinnitus). The response rate was 71%. Distance from the nearest wind turbine and modeled A-weighted SPLs were considered as exposure indicators. One third (33.3%) of the respondents found wind turbine noise annoying outdoors, and one fifth (20.5%) found the noise annoying while indoors. Wind turbine noise was reported as being more annoying than other environmental noises, and self-reported annoyance increased with increasing A-weighted SPLs. Factors such as attitude toward wind turbines and "landscape littering" (visual impact) influenced the perceived annoyance from the wind turbine noise. This study, as with most others, is limited by the cross-sectional design and reliance on self-reported health and well-being indicators; however, analyses focused on predictors of self-reported annoyance, and found that wind turbine noise, attitude toward wind turbines, and attitude toward "landscape littering" explain most of the reported annoyance.

Other Possibly Relevant Studies

A publication based on the self-reporting of 109 individuals who "perceived adverse health effects occurring with the onset of an industrial wind turbine facility" indicated that 102 reported either "altered health or altered quality of life." The authors appropriately noted that this was a survey of self-selected participants who chose to respond to a questionnaire specifically designed to attract those who had health complaints they attributed to wind turbines, with no comparison group. Nevertheless, the authors inappropriately draw the conclusion that "Results of this study suggest an underlying relationship between wind turbines and adverse health effects and support the need for additional studies."[48(p.336)] Such a report cannot provide valid evidence of any relationship for which there is no comparison and is of little if any inferential value.

Researchers at the School of Public Health, University of Sydney, in Australia conducted a study to explore psychogenic explanations for the increase around 2009 of wind farm noise and/or health complaints and the disproportionate corresponding geographic distribution of those complaints.[52] They obtained records of complaints about noise or health from residents living near all 51 wind farms (1634 turbines) operating between 1993 and 2012 from wind farm companies and corroborated with documents such as government public enquiries, news media records, and court affidavits. Of the 51 wind farms, 33 (64.7%) had no record of noise or health complaints, including all wind farms in Western Australia and Tasmania. The researchers identified 129 individuals who had filed complaints, 94 (73%) of whom lived near six wind farms targeted by anti-wind advocacy groups. They observed that 90% of complaints were registered after anti-wind farm groups included health concerns as part of their advocacy in 2009. The authors concluded that their findings were consistent with their psychogenic hypotheses.

Discussion

No cohort or case–control studies were located in this updated review of the peer-reviewed literature. The lack of published case–control studies is less surprising and less critical because there has been no discrete disease or constellation of diseases identified that likely or might be explained by wind turbine noise. Anecdotal reports of symptoms associated with wind turbines include a broad array of nonspecific symptoms, such as headache, stress, and sleep disturbance, that afflict large proportions of the general population and have many recognized risk factors. Retrospectively associating such symptoms with wind turbines or even measured wind turbine noise—as would be necessary in case–control studies—does not prevent recall bias from influencing the results.

Although cross-sectional studies and surveys have the advantage of being relatively simple and inexpensive to conduct, they are susceptible to a number of influential biases. Most importantly, however, is the fact that, because of the simultaneous ascertainment of both exposure (eg, wind turbine noise) and health outcomes or complaints, the temporal sequence of exposure–outcome relationship cannot be demonstrated. If the exposure cannot be established to precede the incidence of the outcome—and not the reverse, that is, the health complaint leads to increased perception of or annoyance with the exposure, as with insomnia headaches or feeling tense/stressed/irritable—the association cannot be evaluated for a possible causal nature.

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Conclusions

A critical review and synthesis of the evidence available from the eight study populations studied to date (and reported in 14 publications) provides some insights into the hypothesis that wind turbine noise harms human health in those living in proximity to wind turbines. These include the following:

- No clear or consistent association is seen between noise from wind turbines and any reported disease or other indicator of harm to human health.
- In most surveyed populations, some individuals (generally a small proportion) report some degree of annoyance with wind turbines; however, further evaluation has demonstrated:
  - Certain characteristics of wind turbine sound such as its intermittence or rhythmicity may enhance reported perceptibility and annoyance;
  - The context in which wind turbine noise is emitted also influences perceptibility and annoyance, including urban versus rural setting, topography, and landscape features, as well as visibility of the wind turbines;
  - Factors such as attitude toward visual effect of wind turbines on the scenery, attitude toward wind turbines in general, personality characteristics, whether individuals benefit financially from the presence of wind turbines, and duration of time wind turbines have been in operation all have been correlated with self-reported annoyance; and
  - Annoyance does not correlate well or at all with objective sound measurements or calculated sound pressures.
- Complaints such as sleep disturbance have been associated with A-weighted wind turbine sound pressures of higher than 40 to 45 dB but not any other measure of health or well-being. Stress was associated with annoyance but not with calculated sound pressures.[63]
- Studies of QOL including physical and mental health scales and residential proximity to wind turbines report conflicting findings–one study (with only 38 participants living within 2.0 km of the nearest wind turbine) reported lower HRQOL among those living closer to wind turbines than respondents living farther away,[66] whereas the largest of all studies (with 853 living within 1500 m of the nearest wind turbine)[67] found that those living closer to wind turbines reported higher QOL and health than those living farther away.[67]

Because these statistical correlations arise from cross-sectional studies and surveys in which the temporal sequence of the exposure and outcome cannot be evaluated, and where the effect of various forms of bias (especially selection/volunteer bias and recall bias) may be considerable, the extent to which they reflect causal relationships cannot be determined. For example, the claims such as "We conclude that the noise emissions of wind turbines disturbed the sleep and caused daytime sleepiness and impaired mental health in residents living within 1.4 km of the two wind turbines installations studied" cannot be substantiated on the basis of the actual study design used and some of the likely biases present.[70]

Notwithstanding the limitations inherent to cross-sectional studies and surveys—which alone may provide adequate explanation for some of the reported correlations—several possible explanations have been suggested for the wind turbines–associated annoyance reported in many of these studies, including attitudinal and even personality characteristics of the survey participants.[69] Pedersen and colleague,[59] who have been involved in the majority of publications on this topic, noted "The enhanced negative response [toward wind turbines] could be linked to aesthetical response, rather than to multi-modal effects of simultaneous auditory and visual stimulation, and a risk of hindrance to psycho-physiological restoration could not be excluded."(p.389) They also found that wind turbines might be more likely to elicit annoyance because some perceive them to be "intrusive" visually and with respect to their noise.[65] Alternative explanations on the basis of evaluation of all health complaints filed between 1993 and 2012 with wind turbine operators across Australia include the influence of anti-wind power activism and the surrounding publicity on the likelihood of health complaints, calling the complaints "communicated diseases."[52]

As noted earlier, the 14 papers meeting the selection criteria for critical review and synthesis were based on only eight independent study groups—three publications were based on the same study group from the Netherlands[58] and four additional publications were based on the combined data from the two Swedish surveys[61,62] or from the combined data from all three. The findings across studies based on analyses of the same data are not independent observations, and therefore the body of available evidence may seem to be larger and more consistent than it should. This observation does not necessarily mean that the relationships observed (or the lack of associations between calculated wind turbines sound pressures and disease or other indicators of health) are invalid, but that consistency across reports based on the same data should not be overinterpreted as independent confirmation of findings. Perhaps more important is that all eight were cross-sectional studies or surveys, and therefore inherently limited in their ability to demonstrate the presence or absence of true health effects.

Recent controlled exposure laboratory evaluations lend support to the notion that reports of annoyance and other complaints may reflect, at least in part, preconceptions about the ability of wind turbine noise to harm health[52,71,72] or even the color of the turbine[73] more than the actual noise emission.

Sixty years ago, Sir Austin Bradford Hill delivered a lecture entitled "Observations and Experiment" to the Royal College of Occupational Medicine. In his lecture, Hill stated that "The observer may well have to be more patient than the experimenter—awaiting the occurrence of the natural succession of events he desires to study; he may well have to be more imaginative—sensing the correlations that lie below the surface of his observations; and he may well have to be more logical and less dogmatic—avoiding as the evil eye the fallacy of '*post hoc ergo propter hoc*,' the mistaking of correlation for causation."74(p.1000)

Although it is typical and appropriate to point out the obvious need for additional research, it may be worth emphasizing that more research of a similar nature—that is, using cross-sectional or survey approaches—is unlikely to be informative, most notably for public policy decisions. Large, well-conducted prospective cohort studies that document baseline health status and can objectively measure the incidence of new disease or health conditions over time with the introduction would be the most informative. On the contrary, the phenomena that constitute wind turbine exposures—primarily noise and visual effect—are not dissimilar to many other environmental (eg, noise of waves along shorelines) and anthropogenic (eg, noise from indoor Heating Ventilation and Air Conditioning or road traffic) stimuli, for which research and practical experience indicate no direct harm to human health.

Sound Components and Health: Infrasound, Low-Frequency Sound, and Potential Health Effects

Introduction

This section addresses potential health implications of infrasound and low-frequency sound because claims have been made that the frequency of wind turbine sound has special characteristics that may present unique health risks in comparison with other sources of environmental sound.

Wind turbines produce two kinds of sound. Gears and generators can make mechanical noise, but this is less prominent than the

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TABLE 1. Human Thresholds for Different Frequencies

Frequency (Hz)	Threshold (dB SPL)
100	27
25	69
10	97

SPL, sound pressure level.

aerodynamic noise of the blades, whose tips may have velocities in excess of 200 mph. Three-bladed turbines often rotate about once every 3 seconds; their "blade-pass" frequency is thus about 1 Hz (Hz: cycle per second). For this reason, the aerodynamic noise often rises and falls about once per second, and some have described the sounds as "whooshing" or "pulsing."

Several studies[44,75,76] have shown that at distances of 300 m or more, wind turbine sounds are below human detection thresholds for frequencies less than 50 Hz. The most audible frequencies (those whose acoustic energies exceed human thresholds the most) are in 500 to 2000 Hz range. At this distance from a single wind turbine, overall levels are typically 35 to 45 dBA.[77,78] These levels can be audible in a typical residence with ambient noise of 30 dBA and windows open (a room with an ambient level of 30 dBA would be considered by most people to be quiet or very quiet). In outdoor environments, sound levels drop about 6 dB for every doubling of the distance from the source, so one would predict levels of 23 to 33 dBA, that is, below typical ambient noise levels in homes, at a distance of 1200 m. For a wind farm of 12 large turbines, Møller and Pedersen[79] predicted a level of 35 dBA at a distance of 453 m.

As noted earlier in this report, sound intensity is usually measured in decibels (dB), with 0 dB SPL corresponding to the softest sounds young humans can hear. Nevertheless, humans hear well only within the frequency range that includes the frequencies most important for speech understanding—about 500 to 5000 Hz. At lower frequencies, hearing thresholds are much higher.[75] Although frequencies lower than 20 Hz are conventionally referred to as "infrasound," sounds in this range can in fact be heard, but only when they are extremely intense (a sound of 97 dB SPL has 10 million times as much energy as a sound of 27 dB; see Table 1).

Complex sounds like those produced by wind turbines contain energy at multiple frequencies. The most complete descriptions of such sounds include dB levels for each of several frequency bands (eg, 22 to 45 Hz, 45 to 90 Hz, 90 to 180 Hz, . . . , 11,200 to 22,400 Hz). It is simpler, and appropriate in most circumstances, to specify overall sound intensity using meters that give full weight to the frequencies people hear well, and less weight to frequencies less than 500 Hz and higher than 5000 Hz. The resulting metric is "A-weighted" decibels or dBA. Levels in dBA correlate well with audibility; in a very quiet place, healthy young people can usually detect sounds less than 20 dBA.

Low-Frequency Sound and Infrasound

Low-frequency noise (LFN) is generally considered frequencies from 20 to 250 Hz, as described earlier in more detail in subsection "Low Frequency and Infrasonic Levels." The potential health implications of low-frequency sound from wind turbines have been investigated in a study of four large turbines and 44 smaller turbines in the Netherlands.[17] In close proximity to the turbines, infrasound levels were below audibility. The authors suggested that LFN could be an important aspect of wind turbine noise; however, they did not link measured or modeled noise levels with any health outcome measure, such as annoyance.

A literature review of infrasound and low-frequency sound concluded that low-frequency sound from wind turbines at residences did not exceed levels from other common noise sources, such as traffic.[44] The authors concluded that a "statistically significant association between noise levels and self-reported sleep disturbance was found in two of the three [epidemiology] studies."[(p.1)]. It has been suggested that LFN from wind turbines causes other and more serious health problems, but empirical support for these claims is lacking.[44]

Sounds with frequencies lower than 20 Hz (ie, infrasound) may be audible at very high levels. At even higher levels, subjects may experience symptoms from very low-frequency sounds—ear pressure (at levels as low as 127 dB SPL), ear pain (at levels higher than 145 dB), chest and abdominal movement, a choking sensation, coughing, and nausea (at levels higher than 150 dB).[80,81] The National Aeronautics and Space Administration considered that infrasound exposures lower than 140 dB SPL would be safe for astronauts; American Conference of Governmental Industrial Hygienists recommends a threshold limit value of 145 dB SPL for third-octave band levels between 1 and 80 Hz.[81] As noted earlier, infrasound from wind turbines has been measured at residential distances and noted to be many orders of magnitude below these levels.

Whenever wind turbine sounds are audible, some people may find the sounds annoying, as discussed elsewhere in this review. Some authors, however, have hypothesized that even inaudible sounds, especially at very low frequencies, could affect people by activating several types of receptors, including the following:

1. Outer hair cells of the cochlea[82];
2. Hair cells of the normal vestibular system,[83] especially the otolith organs[84];
3. Hair cells of the vestibular system after its fluid dynamics have been disrupted by infrasound[82];
4. Visceral graviceptors acting as vibration sensors.[83]

To evaluate these hypotheses, it is useful to review selected aspects of the anatomy and physiology of the inner ear (focusing on the differences between the cochlea and the vestibular organs), vibrotactile sensitivity to airborne sound, and the types of evidence that, while absent at present, could in theory support one or more of these hypotheses.

How the Inner Ear Works

The inner ear contains the cochlea (the organ of hearing) and five vestibular organs (three semicircular canals and two otolith organs, transmitting information about head position and movement). The cochlea and the vestibular organs have one important feature in common—they both use hair cells to convert sound or head movement into nerve impulses that can then be transmitted to the brain. Hair cells are mechanoreceptors that can elicit nerve impulses only when their stereocilia (or sensory hairs) are bent.

The anatomy of the cochlea ensures that its hair cells respond well to airborne sound and poorly to head movement, whereas the anatomy of the vestibular organs optimizes hair cell response to head movement and minimizes response to airborne sound. Specifically, the cochlear hair cells are not attached to the bony otic capsule, and the round window permits the cochlear fluids to move more freely when air-conducted sound causes the stapes to move back and forth in the oval window. Conversely, the vestibular hair cells are attached to the bony otic capsule, and the fluids surrounding them are not positioned between the two windows and thus cannot move as freely in response to air-conducted sound. At the most basic level, this makes it unlikely that inaudible sound from wind turbines can affect the vestibular system.

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Responding to Airborne Sound

Airborne sound moves the eardrum and ossicles back and forth; the ossicular movement at the oval window then displaces inner ear fluid, causing a movement of membranes in the cochlea, with bending of the hair cell stereocilia. Nevertheless, this displacement of the cochlear hair cells depends on the fact that there are two windows separating the inner ear from the middle ear, with the cochlear hair cells positioned between them—whenever the oval window (the bony footplate of the stapes, constrained by a thin annular ligament) is pushed inward, the round window (a collagenous membrane lined by mucous membrane) moves outward, and vice versa. When the round window is experimentally sealed,[85] the cochlea's sensitivity to sound is reduced by 35 dB.

The vestibular hair cells are not positioned between the two cochlear windows, and therefore airborne sound-induced inner ear fluid movement does not efficiently reach them. Instead, the vestibular hair cells are attached to the bone of the skull so that they can respond faithfully to head movement (the cochlear hair cells are not directly attached to the skull). As one might expect, vestibular hair cells can respond to head vibration (bone-conducted sound), such as when a tuning fork is held to the mastoid. Very intense airborne sound can also make the head vibrate; people with severe conductive hearing loss can hear airborne sound in this way, but only when the sounds are made 50 to 60 dB more intense than those audible to normal people.

The cochlea contains two types of hair cells. It is often said that we hear with our inner hair cells (IHCs) because all the "type I" afferent neurons that carry sound-evoked impulses to the brain connect to the IHCs. The outer hair cells (OHCs) are important as "preamplifiers" that make it possible to hear very soft sounds; they are exquisitely tuned to specific frequencies, and when they move they create fluid currents that then displace the stereocilia of the IHCs.

Although more numerous than the IHCs, the OHCs receive only very scanty afferent innervation, from "type II" neurons, the function of which is unknown. Salt and Hullar[82] have pointed out that OHCs generate measurable electrical responses called cochlear microphonics to very low frequencies (eg, 5 Hz) at levels that are presumably inaudible to the animals and have hypothesized that the type II afferent fibers from the OHCs might carry this information to the brain. Nevertheless, it seems that no one has ever recorded action potentials from type II cochlear neurons, nor have physiological responses other than cochlear microphonics been recorded in response to inaudible sounds.[86,87] In other words, as Salt and Hullar[82] acknowledge, "The fact that some inner ear components (such as the OHC) may respond to [airborne] infrasound at the frequencies and levels generated by wind turbines does not necessarily mean that they will be perceived or disturb function in any way."[(p.19)]

Responses of the Vestibular Organs

As previously noted, vestibular hair cells are efficiently coupled to the skull. The three semicircular canals in each ear are designed to respond to head rotations (roll, pitch, yaw, or any combination). When the head rotates, as in shaking the head to say "no," the fluid in the canals lags behind the skull and bends the hair cells. The otolith organs (utricle and saccule) contain calcium carbonate crystals (otoconia) that are denser than the inner ear fluid, and this allows even static head position to be detected; when the head is tilted, gravitational pull on the otoconia bends the hair cells. The otolith organs also respond to linear acceleration of the head, as when a car accelerates.

Many people complaining about wind turbines have reported dizziness, which can be a symptom of vestibular disorders; this has led to suggestions that wind turbine sound, especially inaudible infrasound, can stimulate the vestibular organs.[83,84] Pierpont[83] introduced a term "Wind Turbine Syndrome" based on a case series of 10 families who reported symptoms that they attributed to living near wind turbines. The author invited people to participate if they thought they had symptoms from living in the vicinity of wind turbines; this approach introduces substantial selection bias that can distort the results and their corresponding significance. Telephone interviews were conducted; no medical examination, diagnostic studies or review, and documentation of medical records were conducted as part of the case series. Noise measurements were not provided. Nonetheless, the author described a collection of nonspecific symptoms that were described as "Wind Turbine Syndrome." The case series, at the time of preparation of this review, has not been published in the peer-reviewed scientific literature. Although not medically recognized, advocates of this "disorder" suggest that wind turbines produce symptoms, such as headaches, memory loss, fatigue, dizziness, tachycardia, irritability, poor concentration, and anxiety.[88]

To support her hypotheses, Pierpont cited a report by Todd et al[89] that demonstrated human vestibular responses to bone-conducted sound at levels below those that can be heard. But as previously noted, this effect is not surprising because the vestibular system is designed to respond to head movement (including head vibration induced by direct contact with a vibrating source). The relevant issue is how the vestibular system responds to airborne sound, and here the evidence is clear. Vestibular responses to airborne sound require levels well above audible thresholds.[90,91] Indeed, clinical tests of vestibular function using airborne sound use levels in excess of 120 dB, which raise concerns of acoustic trauma.[92]

Salt and Hullar[82] acknowledge that a normal vestibular system is unlikely to respond to inaudible airborne sound—"Although the hair cells in other sensory structures such as the saccule may be tuned to infrasonic frequencies, auditory stimulus coupling to these structures is inefficient so that they are unlikely to be influenced by airborne infrasound."[(p.12)] They go on to hypothesize that infrasound may cause endolymphatic hydrops, a condition in which one of the inner ear fluid compartments is swollen and may disturb normal hair cell function. But here, too, they acknowledge the lack of evidence—"... it has never been tested whether stimuli in the infrasound range cause endolymphatic hydrops."[(p.19)] In previous research, Salt[93] was able to create temporary hydrops in animals using airborne sound, but only at levels (115 dB at 200 Hz) that are many orders of magnitude higher than levels that could exist at residential distances from wind turbines.

Human Vibrotactile Sensitivity to Airborne Sound

Very loud sound can cause head and body vibration. As previously noted, a person with absent middle ear function but an intact cochlea may hear sounds at 50 to 60 dB SPL. Completely deaf people can detect airborne sounds using the vibrotactile sense, but only at levels far above hearing threshold, for example, 128 dB SPL at 16 Hz.[94] Vibrotactile sensation depends on receptors in the skin and joints.

Pierpont[83] hypothesized that "visceral graviceptors,"[95,96] which contain somatosensory receptors, could detect airborne infrasound transmitted from the lungs to the diaphragm and then to the abdominal viscera. These receptors would seem to be well suited to detect body tilt or perhaps whole-body vibration, but there is no evidence that airborne sound could stimulate sensory receptors in the abdomen. Airborne sound is almost entirely reflected away from the body; when Takahashi et al[97] used airborne sound to produce chest or abdominal vibration that exceeded ambient body levels, levels had to exceed 100 dB at 20 to 50 Hz.

Further Studies of Note

The influence of preconception on mood and physical symptoms after exposure to LFN was examined by showing 54 university

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students one of two series of short videos that either promoted or dispelled the notion that sounds from wind turbines had health effects, then exposing subjects to 10 minutes of quiet period followed by infrasound (40 dB at 5 Hz) generated by computer software, and assessing mood and a series of physical symptoms.[71] In a double-blind protocol, participants first exposed to either a "high-expectancy" presentation included first-person accounts of symptoms attributed to wind turbines or a "low-expectancy" presentation showed experts stating scientific positions indicating that infrasound does not cause symptoms. Participants were then exposed to 10 minutes of infrasound and 10 minutes of sham infrasound. Physical symptoms were reported before and during each 10-minute exposure. The study showed that healthy volunteers, when given information designed to invoke either high or low expectations that exposure to infrasound causes symptom complaints, reported symptoms that were consistent with the level of expectation. These data demonstrate that the participants' expectations of the wind turbine sounds determined their patterns of self-reported symptoms, regardless of whether the exposure was to a true or sham wind turbine sound. The concept known as a "nocebo" response, essentially the opposite of a placebo response, will be discussed in more detail later in this report. A nocebo response refers to how a preconceived negative reaction can occur in anticipation of an event.[98]

A further study assessed whether positive or negative health information about infrasound generated by wind turbines affected participants' symptoms and health perceptions in response to wind farm sound.[72] Both physical symptoms and mood were evaluated after exposure to LFN among 60 university students first shown high-expectancy or low-expectancy short videos intended to promote or dispel the notion that wind turbines sounds impacted health. One set of videos presented information indicating that exposure to wind turbine sound, particularly infrasound, poses a health risk, whereas the other set presented information that compared wind turbine sound to subaudible sound created by natural phenomena such as ocean waves and the wind, emphasizing their positive effects on health. Students were continuously exposed during two 7-minute listening sessions to both infrasound (50.4 dB, 9 Hz) and audible wind farm sound (43 dB), which had been recorded 1 km from a wind farm, and assessed for mood and a series of physical symptoms. Both high-expectancy and low-expectancy groups were made aware that they were listening to the sound of a wind farm and were being exposed to sound containing both audible and subaudible components and that the sound was at the same level during both sessions. Participants exposed to wind farm sound experienced a placebo response elicited by positive preexposure expectations, with those participants who were given expectations that infrasound produced health benefits reporting positive health effects. They concluded that reports of symptoms or negative effects could be nullified if expectations could be framed positively.

University students exposed to recorded sounds from locations 100 m from a series of Swedish wind turbines for 10 minutes were assessed for parameters of annoyance.[99] Sound was played at a level of 40 dBAeq (the "eq" refers to the average level over the 10-minute exposure). After the initial exposure, students were exposed to an additional 3 minutes of noise while filling out questionnaires. Authors reported that ratings of annoyance, relative annoyance, and awareness of noise were different among the different wind turbine recordings played at equivalent noise levels. Various psychoacoustic parameters (sharpness, loudness, roughness, fluctuation strength, and modulation) were assessed and then grouped into profiles. Attributes such as "lapping," "swishing," and "whistling'' were more easily noticed and potentially annoying, whereas "low frequency" and "grinding" were associated with less intrusive and potentially less annoying sounds.

Adults exposed to sounds recorded from a 1.5 MV Korean wind turbine were assessed for the degree of noise annoyance.[100] Over a 40-minute period, subjects were exposed to a series of 25 random 30-second bursts of wind turbine noise, separated by at least 10 seconds of quiet between bursts. Following a 3-minute quiet period, this pattern was repeated. Participants reported their annoyance on a scale of 1 to 11. Authors found that the amplitude modulation of wind turbine noise had a statistically significant effect on the subjects' perception of noise annoyance.

The effect of psychological parameters on the perception of noise from wind turbines was also assessed in Italian adults from both urban and rural areas. Recorded sounds from different distances (150 m, 250 m, and 500 m) away from wind turbines were played while pictures of wind turbines were shown and subjects described their reaction to the pictures.[73] Pictures differed in color, the number of wind turbines, and distance from wind turbines. Pictures had a weak effect on individual reactions to the number of wind turbines; the color of the wind turbines influenced both visual and auditory individual reactions, although in different ways.

Epilepsy and Wind Turbines

Rapidly changing visual stimuli, such as flashing lights or oscillating pattern changes, can trigger seizures in susceptible persons, including some who never develop spontaneous seizures; stimuli that change at rates of 12 to 30 Hz are most likely to trigger seizures.[101] Rotating blades (of a ceiling fan, helicopter, or wind turbine) that interrupt light can produce a flicker, leading to a concern that wind turbines might cause seizures. Nevertheless, large wind turbines (2 MW or more) typically rotate at rates less than 1 Hz; with three blades, the frequency of light interruption would be less than 3 Hz, a rate that would pose negligible risk to developing a photoepileptic seizure.[102]

Smedley et al[103] applied a complex simulation model of seizure risk to wind turbines, assuming worst-case conditions—a cloudless day, an observer looking directly toward the sun with wind turbine blades directly between the observer and the sun, but with eyes closed (which scatters the light more broadly on the retina); they concluded that there would be a risk of seizures at distances up to nine times the turbine height, but only when blade frequency exceeds 3 Hz, which would be rare for large wind turbines. Smaller turbines, typically providing power for a single structure, often rotate at higher frequencies and might pose more risk of provoking seizures. At the time of preparation of this report, there has been no published report of a photoepileptic seizure being triggered by looking at a rotating wind turbine.

Sleep and Wind Turbines

Sleep disturbance is relatively common in the general population and has numerous causes, including illness, depression, stress, and the use of medications, among others. Noise is well known to be potentially disruptive to sleep. The key issue with respect to wind turbines is whether the noise is sufficiently loud to disrupt sleep. Numerous environmental studies of noise from aviation, rail, and highways have addressed sleep implications, many of which are summarized in the WHO's position paper on Nighttime Noise Guidelines (Fig. 7).[104] This consensus document is based on an expert analysis of environmental noise from sources other than wind turbines, including transportation, aviation, and railway noise. The WHO published the figure (Fig. 7) to indicate that significant sleep disturbance from environmental noise begins to occur at noise levels greater than 45 dBA. This figure is based on an analysis of pooled data from 24 different environmental noise studies, although no wind turbine–related noise studies were included in the analysis. Nonetheless, the studies provide substantial data on environmental noise exposure that can be contrasted with noise levels associated with wind turbine operations to enable one to draw reasonable inferences.

In contrast to the WHO position, an author in an editorial claimed that routine wind turbine operations that result in noise

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levels less than 45 dBA can have substantial effects on sleep, with corresponding adverse health effects.[105] Another author, however, challenged the basis of the assertion by pointing out that Hanning had ignored 17 reviews on the topic with alternative perspectives and different results.[106]

Sleep disturbance is a potential extra-auditory effect of noise, and research has shown a link between wind turbine noise and sleep disruption.[4,57,63,66,107] As with of the other variables reviewed, quantifying sleep quality is typically done with coarse measures. In fact, this reviewer identified no studies that used a multi-item validated sleep measure. Research studies typically rely on a single item (sometimes answered yes/no) to measure sleep quality. Such coarse measurement of sleep quality is unfortunate because impaired sleep is a plausible pathway by which wind turbine noise exposure may impact both psychological well-being and physical health.

Disturbed sleep can be associated with adverse health effects.[108] Awakening thresholds, however, depend on both physical and psychological factors. Signification is a psychological factor that refers to the meaning or attitude attached to a sound. Sound with high signification will awaken a sleeper at lower intensity than sound lacking signification.[108] As reviewed above, individuals often attach attitudes to wind turbine sound; as such, wind turbine sleep disruption may be impacted by psychological factors related to the sound source.

Shepherd et al[66] found a significant difference in perceived sleep quality between their wind farm and comparison groups, with the wind farm group reporting worse sleep quality. In the wind farm group, noise sensitivity was strongly correlated with sleep quality. In both the wind farm and comparison groups, sleep quality showed similar strong positive relationships with physical HRQL and psychological HRQL. Pedersen[63] found that sound-level exposure was associated with sleep interruption in two of three studies reviewed; however, the effect sizes associated with sound exposure were minimal.

Bakker et al[57] found that noise exposure was related to sleep disturbance in quiet areas ($d = 0.40$) but not for individuals in noisy areas ($d = 0.02$). Nevertheless, when extreme sound exposure groups were composed,[57] data showed that individuals living in high sound areas (greater than 45 dBA) had significantly greater sleep disruption than subjects in low sound areas (less than 30 dBA). Annoyance ratings were more strongly associated with sleep disruption.[57] Furthermore, when[57] structural equation models (SEMs) were applied, the direct association between sound level and sleep disruption was lost and annoyance seemed to mediate the effect of wind turbine sound on sleep disturbance. Across the reviewed studies it seems that sleep disruption was associated with sound-level exposure; however, the associations were weak and annoyance ratings were more strongly and consistently associated with self-reported sleep disruption.

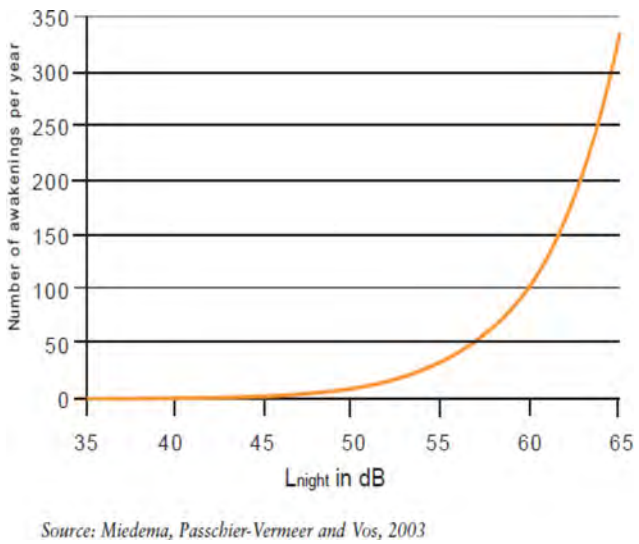

FIGURE 7. Worst-case prediction of noise-induced behavioral awakenings. Adapted from WHO[104] (Chapter 3); Miedema et al.[163]

Conclusions

Infrasound and low-frequency sound can be generated by the operation of wind turbines; however, neither low-frequency sound nor infrasound in the context of wind turbines or in experimental studies has been associated with adverse health effects.

Annoyance, Wind Turbines, and Potential Health Implications

The potential effect of noise on health may occur through both physiological (sleep disturbance) and psychological pathways. Psychological factors related to noise annoyance reported in association with wind turbine noise will be reviewed and analyzed. A critique of the methodological adequacy of the existing wind turbine research as it relates to psychological outcomes will be addressed.

As noted earlier, "annoyance" has been used as an outcome measure in environmental noise studies for many decades. Annoyance is assessed via a questionnaire. Because annoyance has been associated under certain circumstances with living in the vicinity of wind turbines, this section examines the significance of annoyance, risk factors for reporting annoyance in the context of wind turbines, and potential health implications.

For many years, it has been recognized that exposure to high noise levels can adversely affect health[109,110] and that environmental noise can adversely affect psychological and physical health.[111] Key to evaluating the health effects of noise exposure—like any hazard—is a thorough consideration of noise intensity and duration. When outcomes are broadened to include more subjective qualities like annoyance and QOL, additional psychological factors must be studied.

Noise-related annoyance is a subjective psychological condition that may result in anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation, or exhaustion.[112] Annoyance is primarily identified using standardized self-report questionnaires. Well-established psychiatric conditions like major depressive disorder are also subjective states that are most often identified by self-report questionnaires. Despite its subjective nature, noise annoyance was included as a negative health outcome by the WHO in their recent review of disease burden related to noise exposure.[112] The inclusion of annoyance with conditions like cardiovascular disease reinforces its status as a legitimate primary health outcome for environmental noise research.

This section reviews the literature on the effect of wind turbines, including noise-related annoyance and its corresponding effect on health, QOL, and psychological well-being. "Quality of life" is a multidimensional concept that captures subjective aspects of an individual's experience of functioning, well-being, and satisfaction across the physical, mental, and social domains of life. The WHO defines QOL as "an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept affected in complex ways by the person's physical health, psychological status, personal beliefs, social relationships and their relationship to salient features of their environment".[113(p1404)] Numerous well-validated QOL measures are available, with the SF-12 and SF-36[114] and the WHO Quality of Life—Short Form (WHOQLO-BREF[115]) being among the most commonly used. Quality of life measures have been widely

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adopted as primary outcomes for clinical trials and cost-effectiveness research.

Meta-analysis is a quantitative method for summarizing the relative strength of an effect or relationship as observed across multiple independent studies.[116] The increased application of meta-analysis has had a considerable effect on how literature reviews are approached. Currently, more than 20 behavioral science journals require that authors report measures of effect size along with tests of significance.[117] The use of effect size indicators enhances the comparability of findings across studies by changing the reported outcome statistics to a common metric. In behavioral health, the most frequently used effect size indicators are the Cohen d[118] and r the zero-order (univariate) correlation coefficient.[117] An additional advantage of reporting outcomes as effect size units is that benchmarks exist for judging the magnitude of these (significant) differences. Studies reviewed below report an array of statistical analyses (the t test, analysis of variances, odds ratios, and point-biserial and biserial correlations), some of which are not suitable for conversion into the Cohen d; thus, following the recommendations of McGrath and Meyer,[117] r will be used as the common effect size measure for evaluating studies. As reference points, r between 0.10 and 0.23 represents small effects, r between 0.24 and 0.36 represents medium effects, and r of 0.37 and greater represent large effects.[117] Although these values offer useful guidelines for comparing findings, it is important to realize that, in health-related research, very small effects with $r < 0.10$ can be of great importance.[119]

Noise Sensitivity

Noise sensitivity is a stable and normally distributed psychological trait,[120] but predicting who will be annoyed by sound is not a straightforward process.[121] Noise sensitivity has been raised as a major risk factor for reporting annoyance in the context of environmental noise.[156] Noise sensitivity is a psychological trait that affects how a person reacts to sound. Despite lacking a standard definition, people can usually reliably rate themselves as low (noise tolerant), average, or high on noise sensitivity questionnaires; those who rate themselves as high are by definition noise sensitive.

Noise-sensitive individuals react to environmental sound more easily, evaluate it more negatively, and experience stronger emotional reactions than noise tolerant people.[122–124,146,153–156,159–161] Noise sensitivity is not related to objectively measured auditory thresholds,[125] intensity discrimination, auditory reaction time, or power-function exponents for loudness.[120] Noise sensitivity reflects a psychophysiological process with neurocognitive and psychological features. Noise-sensitive individuals have noise "annoyance thresholds" approximately 10 dB lower than noise tolerant individuals.[123] Noise sensitivity has been described as increasing a person's risk for experiencing annoyance when exposed to sound at low and moderate levels.[4,157]

Noise-Related Annoyance

Noise sensitivity and noise-related annoyance are moderately correlated ($r = 0.32$[120]) but not isomorphic. The WHO[112] defines noise annoyance as a subjective experience that may include anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation, or exhaustion. A survey of an international group of noise researchers indicated that noise-related annoyance is multifaceted and includes both behavioral and emotional features.[126] This finding is consistent with Job's[122] definition of noise annoyance as a state associated with a range of reactions, including frustration, anger, dysphoria, exhaustion, withdrawal, and helplessness.

Annoyance and Wind Turbine Sounds

As noted elsewhere in this review, Pedersen and colleagues[58,61,62,65] conducted the world's largest epidemiological studies of people living in the vicinity of wind turbines. These studies have been discussed in detail in the epidemiological studies section of this review. Other authors have also addressed annoyance in the context of living near wind turbines.[57,61,125,127,128] Pedersen[63] later compared findings from the three cross-sectional epidemiological studies to identify common outcomes. Across all three studies, SPLs were associated with annoyance outside (r between 0.05 and 0.09) and inside of the people's homes (r between 0.04 and 0.05). These effect sizes were all less than the small effect boundary of 0.10, meaning that sound levels played a minor role in annoyance. The percentages of people reporting annoyance with wind turbine noise ranged from 7% to 14% for indoor exposure and 18% to 33% for outside exposure.[58,61] These rates are similar to those reported for exposure to other forms of environmental noise.[129]

The dynamic nature of wind turbine sound may make it more annoying than other sources of community noise according to Pedersen et al.[58] They compared self-reported annoyance from other environmental noise exposure studies (aircraft, railways, road traffic, industry, and shunting yards) with annoyance from wind turbine sound. Proportionally, more subjects were annoyed with wind turbine sound at levels lower than 50 dB than with all other sources of noise exposure, except for shunting yards. Pedersen and Waye[107,128] reported that the sound characteristics of swishing ($r = 0.70$) and whistling ($r = 0.62$) were highly correlated with annoyance to wind turbine sound. Others have reported similar findings. One author has suggested that wind turbine sound may have acoustic qualities that may make it more annoying at certain noise levels.[80] Other theories for symptoms described in association with living near wind turbines have also been proposed.[139]

Annoyance associated with wind turbine sounds tends to show a linear association. Sound levels, however, explain only between 9% ($r = 0.31$) and 13% ($r = 0.36$) of the variance in annoyance ratings.[57,61] Therefore, SPLs seem to play a significant, albeit limited, role in the experience of annoyance associated with wind turbines, a conclusion similar to that reached by Knopper and Ollson.[4]

Nonacoustical Factors Associated With Annoyance

Although noise levels and noise sensitivity affect the risk of a person reporting annoyance, nonacoustic factors also play a role, including the visual effect of the turbines, whether a person derives economic benefit from the turbines and the type of terrain where one lives.[4] Pedersen and Waye[61] assessed the effect of visual/perceptual factors on wind turbine–related annoyance; all of the variables described above were significantly related to self-reported annoyance after controlling for SPLs. Nevertheless, when these variables were evaluated simultaneously, only attitude to the visual effect of the turbines remained significantly related to annoyance ($r = 0.41$, which can be interpreted as a large effect) beyond sound exposure. Pedersen and Waye[128] also found visual effect to be a significant factor in addition to sound exposure for self-reported annoyance to wind turbine sounds. Pedersen et al[58] explored the effect of visual attitude on wind turbine sound-related annoyance. Logistic regression showed that sound levels, noise sensitivity, attitudes toward wind turbines, and visual effect were all significant independent predictors of annoyance. Nevertheless, visual attitudes showed an effect size of $r = 0.27$ (medium effect), whereas noise sensitivity had an r of 0.09. Other authors have also found the visual effect of wind turbines to be related to annoyance ratings.[130] Results from multiple studies support the conclusion that visual effect contributes to wind turbine annoyance,[4] with this review finding visual effect to have an effect size in the medium to large range. Nevertheless, given that noise sensitivity and visual attitude are consistently correlated ($r = 0.19$ and $r = 0.26$, respectively),[58,61] it is possible that visual effect enhances

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annoyance through multisensory (visual and auditory) activation of the noise-sensitivity trait.

Economic Benefit, Wind Turbines, and Annoyance

Some studies have indicated that people who derive economic benefit from wind turbines are less likely to report annoyance. Pedersen et al[58] found that people who benefited economically ($n = 103$) from wind turbines reported significantly less annoyance despite being exposed to relatively high levels of wind turbine noise. The annoyance mitigating effect of economic benefit was replicated in Bakker et al.[57] The mitigation effect of economic benefit seems to be within the small effect size range ($r = 0.15$).[57] In addition, because receiving economic benefit represents a personal choice to have wind turbines on their property in exchange for compensation, the involvement of subject selection factors (ie, noise tolerance) requires additional study.

Annoyance, Quality of Life, Well-being, and Psychological Distress

The largest cross-sectional epidemiological study of wind turbine noise on QOL was conducted in northern Poland.[67] Surveys were completed by 1277 adults (703 women and 574 men), aged 18 to 94 years, representing a 10% two-stage random sample of the selected communities. Although the response rate was not reported, participants were sequentially enrolled until a 10% sample was achieved, and the proportion of individuals invited to participate but unable or refusing to participate was estimated at 30% (B. Mroczek, personal communication). Proximity of residence was the exposure variable, with 220 (17.2%) respondents within 700 m, 279 (21.9%) between 700 and 1000 m, 221 (17.3%) between 1000 and 1500 m, and 424 (33.2%) residing more than 1500 m from the nearest wind turbine. Several indicators of QOL, measured using the SF-36, were analyzed by proximity to wind turbines. The SF-36 consists of 36 questions divided into the following subscales: physical functioning, role-functioning physical, bodily pain, general health, vitality, social functioning, role-functioning emotional, and mental health. An additional question concerning health change was included, as well as the Visual Analogue Scale for health assessment. It is unclear whether age, sex, education, and occupation were controlled. The authors report that within all subscales, those living closest to wind farms reported the best QOL, and those living farther than 1500 m scored the worst. They concluded that living in close proximity to wind farms does not result in worsening of the QOL.[67] The authors recommend that subsequent research evaluate the reasons for the higher QOL and health indicators associated with living in closer proximity to wind farms. They speculated that these might include economic factors such as opportunities for employment with or renting land to the wind farm companies.

Individuals living closer to wind farms reported higher levels of mental health ($r = 0.11$), physical role functioning ($r = 0.07$), and vitality ($r = 0.10$) than did those living farther away.[67] Nevertheless, the implications of the study[67] are unclear, as the authors did not estimate sound-level exposure or obtain noise annoyance ratings from their subjects. Overall, with the exception of the study by Mroczek et al,[67] noise annoyance demonstrated a consistent small to medium effect on QOL and psychological well-being.

A study a year earlier of 39 individuals in New Zealand came to different conclusions than the Polish study.[131] Survey results from 39 residents located within 2 km of a wind turbine in the South Makara Valley in New Zealand were compared with 139 geographically and socioeconomically matched individuals who resided at least 8 km from any wind farm. The response rates for both the proximal and more distant study groups were poor, that is, 34% and 32%, respectively, although efforts were made to blind respondents to the study hypotheses. No other indicator of exposure to wind turbines was included beyond the selection of individuals from within 2 km or beyond 8 km of a wind turbine, so actual or calculated wind turbine noise exposures were not available. Subjective HRQOL scales were used to describe and compare the self-reported physical, psychological, and social well-being for each group. Health-related quality of life measures are believed to provide an alternative approach to direct health assessment in that decrements in well-being are assumed to be sensitive to and reflect possible underlying health effects. The authors reported statistically significant differences between the groups in some HRQOL domain scores, with residents living within 2 km of a turbine installation reporting lower mean physical HRQOL domain score (including lower component scores for sleep quality and self-reported energy levels) and lower mean environmental QOL scores (including lower component scores for considering one's environment to be less healthy and being less satisfied with the conditions of their living space). The wind farm group scored significantly lower on physical HRQL ($r = 0.21$), environmental QOL ($r = 0.19$), and overall HRQL ($r = 0.10$) relative to the comparison group. Although the psychological QOL ratings were not significantly different ($P = 0.06$), the wind farm group also scored lower on this measure ($r = 0.16$). In the wind farm group, noise sensitivity was strongly correlated with noise annoyance ($r = 0.44$), psychological HRQL ($r = 0.40$), and social HRQOL ($r = 0.35$). These correlations approach or exceed the large effect size boundary ($r > 0.37$ suggested by Cohen).

There were no differences seen for social or psychological HRQOL domain scores. The turbine group also reported lower amenity scores, which are based on responses to two general questions—"I am satisfied with my neighborhood/living environment," and "My neighborhood/living environment makes it difficult for me to relax at home." No differences were reported between groups for traffic or neighborhood noise annoyance. Lack of actual wind turbine and other noise source measurements, combined with the low response rate (both noted by the authors as limitations), limits the inferential value of this study because it might pertain to wind turbine emissions.

Across three studies, Pedersen[63] found that outdoor annoyance with turbine sound was associated with tension and stress ($r = 0.05$ to 0.06) and irritability ($r = 0.05$ to 0.08), qualities associated with psychological distress. Bakker et al[57] also found that psychological distress was significantly related to wind turbine sound ($r = 0.16$), reported outside annoyance ($r = 0.18$) and inside annoyance ($r = 0.24$). Taylor et al[69] found that subjects living in areas with a low probability of hearing turbine noise reported significantly higher levels of positive affect than those living in moderate or high noise areas ($r = 0.24$), suggesting greater well-being for the low noise group.

Personality Factors and Wind Turbine Sound

Personality psychologists use five bipolar dimensions (neuroticism, extraversion-introversion, openness, agreeableness, and conscientiousness) to organize personality traits.[132] Two of these dimensions, neuroticism and extraversion-introversion, have been studied in relation to noise sensitivity and annoyance. Neuroticism is characterized by negative emotional reactions, sensitivity to harmful cues in the environment, and a tendency to evaluate situations as threatening.[133] Introversion (the opposite pole of extraversion) is characterized by social avoidance, timidity, and inhibition.[133] A strong negative correlation has been shown between noise sensitivity (self-ratings) and self-rated extraversion,[125] suggesting that introverts are more noise sensitive. Introverts experience a greater disruption in vigilance when exposed to low-intensity noise than do extroverts.[134] Extroverts and introverts differ in terms of stimulation thresholds with introverts being more easily overstimulated than extroverts.[135] Despite these studies, the potential link between broad personality domains and noise annoyance remains unclear.

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Taylor et al[69] explored the role of neuroticism, attitude toward wind turbines, negative oriented personality (NOP) traits (negative affectivity, frustration intolerance), and self-reported nonspecific somatic symptoms (NSS) in reaction to wind turbine noise. Despite one of the few peer-reviewed studies of personality and noise sensitivity, it only achieved a 10% response rate, which raises questions as to the representativeness of the findings. Nonetheless, the study sample reported a moderately positive attitude toward wind turbines in general and seemed representative of the local community. In the study by Taylor et al,[69] zero-order correlations showed that estimated sound levels were significantly related to perceived turbine noise ($r = 0.33$) and reduced positive affect ($r = -0.32$) but not to nonspecific symptoms ($r = 0.002$), whereas neuroticism and NOP traits were significantly related to NSS (r of 0.44 and 0.34, respectively). Multivariate analysis suggested that high NOP traits moderated the relationship between perceived noise and the report of NSS; that is, subjects with higher NOP traits reported significantly more NSS than did subjects low in NOP across the range of perceived loudness of noise.

Nocebo Response

The nocebo response refers to new or worsening symptoms produced by negative expectations.[98,136] When negatively worded pretreatment information ("could lead to a slight increase in pain") was given to a group of chronic back pain patients, they reported significantly more pain ($r = 0.38$) and had worse physical performance ($r = 0.36$).[98] These effect sizes are within the moderate to large ranges and reflect a meaningful adverse effect for the negative information contributing to the nocebo response. The effect of providing negative information regarding wind turbines prior to exposure to infrasound has been experimentally explored. Crichton et al[137] exposed college students to sham and true infrasound under high-expectancy (ie, adverse health effects from wind turbines) and low-expectancy (ie, no adverse health effects) conditions. The high-expectancy group received unfavorable information from TV and Internet accounts of symptoms associated with wind farm noise, whereas the low-expectancy group heard experts stating that wind farms would not cause symptoms. Symptoms were assessed pre- and postexposure to actual and sham infrasound. The high-expectancy group reported significantly more symptoms ($r = 0.37$) and greater symptom intensity ($r = 0.37$) following both sham and true infrasound exposure ($r = 0.65$ and 0.48, respectively). The effect sizes were similar to those found in medical research on the nocebo response. These findings demonstrate that exposing individuals to negative information can increase symptom reporting immediately following exposure. The inclusion of information from TV and the Internet suggests that similar reactions may occur in real-world settings.

A study by Deignan et al[138] analyzed newspaper coverage of wind turbines in Canada and found that media coverage might contribute to nocebo responses. Newspaper coverage contained fright factor words like "dread," "poorly understood by science," "inequitable," and "inescapable exposure"; the use of "dread" and "poorly understood by science" had increased from 2007 to 2011. These results document the use of fright factor words in the popular coverage of wind turbine debates; exposure to information containing these words may contribute to nocebo reactions in some people.

Wind turbines, similar to multiple technologies, such as power lines, cell phone towers, and WiFi signals, among others, have been associated with clusters of unexplained symptoms. Research suggests that people are increasingly worried about the effect of modern life (in particular emerging technologies) on their health (modern health worries [MHW]).[140]) Modern Health Worries are moderately correlated with negative affect ($r = 0.23$) and, like the nocebo response, are considered psychogenic in origin. The expansion of wind turbine energy has been accompanied by substantial positive and negative publicity that may contribute to MHW and nocebo responses among some people exposed to this information. Health concerns have also been raised about the potential of electromagnetic fields associated with wind turbine operations; however, a recent study indicated that magnetic fields in the vicinity of wind turbines were lower than those produced by common household items.[140]

Chapman et al[52] explored the pattern of formal complaints (health and noise) made in relation to 51 wind farms in Australia from 1993 to 2012. The authors suggest that their study is a test of the psychogenic (nocebo or MHW) hypothesis. The findings showed that very few complaints were formally lodged; only 129 individuals in Australia formally or publically complained during the time period studied, and the majority of wind farms had no complaint made against them. The authors found that complaints increased around 2009 when "wind turbine syndrome" was introduced. On the basis of these findings, the authors conclude that nocebo effects likely play an important role in wind farm health complaints. But the authors do report that the vast majority of complaints (16 out of 18) were filed by individuals living near large wind farms ($r = 0.32$). So while few individuals complain, those who do almost exclusively live near large wind farms. Nevertheless, it is important to note that filing a formal or public complaint is a complex sociopolitical action, not a health-related outcome. Furthermore, analysis of data provided in Table 2 of the Chapman[54] study shows that the strongest predictor of a formal complaint was the presence of an opposition group in the area of the wind farm. A review of Table 2 shows that opposition groups were present in 15 of the 18 sites that filled complaints, whereas there was only one opposition group in the 33 areas that did not file a complaint ($r = 0.82$). Therefore, the relevance of this study for understanding health effects of wind turbines is limited. Chapman has also addressed the multitude of reasons why some Australian home owners may have left their homes and attributed the decision to wind turbines.[54] Gross[140] provides a community justice model designed to counter the potential for nocebo or psychogenic response to wind farm development. This method was pilot tested in one community and showed the potential to increase the sense of fairness for diverse community members. No empirical data were gathered during the pilot study so the effect of method cannot be formally evaluated.

Conclusions

Annoyance is a recognized health outcome measure that has been used in studies of environmental noise for many decades. Noise levels have been shown to account for only a modest portion of self-reported annoyance in the context of wind turbines ($r = 0.35$).[4] Noise sensitivity, a stable psychological trait, contributes equally to exposure in explaining annoyance levels ($r = 0.37$). Annoyance associated with wind turbine noise shows a consistent small to medium adverse effect on self-rated QOL and psychological well-being. Given the coarseness of measures used in many studies, the magnitude of these findings are likely attenuated and underestimate the effect of annoyance on QOL. Visual effect increases annoyance beyond sound exposure and noise sensitivity, but at present there is insufficient research to conclude that visual effect operates separately from noise sensitivity because the two variables are correlated. Wind turbine development is subject to the same global psychogenic health worries and nocebo reactions as other modern technologies.[139]

Economic benefit mitigates the effect of wind turbine sound; however, research is needed to clarify the potential confounding role of (self) selection in this finding. The most powerful multivariate model reviewed accounted for approximately 50% ($r = 0.69$) of the variance in reported annoyance, leaving 50% unexplained. Clearly other relevant factors likely remain unidentified. Nevertheless, it is not unusual for there to be a significant percentage of unexplained variance in biomedical or social science research. For example, a meta-analysis of postoperative pain (a subjective experience),

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covering 48 studies and 23,037 subjects, found that only 54% ($r = 0.73$) of the variance in pain ratings could be explained by the variables included in the studies.[144] Wind turbine development is subject to the same global psychogenic health worries and nocebo reactions as other modern technologies. Therefore, communities, government agency, and companies would be well advised to adopt an open, transparent, and engaging process when debating the potential effect of wind turbine sites. The vast majority of findings reviewed in this section were correlational and, therefore, do not imply causality, and that other as of yet unidentified (unmeasured) factors may be associated with or responsible for these findings.

DISCUSSION

Despite the limitations of available research related to wind turbines and health, inferences can be drawn from this information, if used in concert with available scientific evidence from other environmental noise studies, many of which have been reviewed and assessed for public policy in the WHO's Nighttime Noise Guidelines.[104] A substantial database on environmental noise studies related to transportation, aviation, and rail has been published.[147] Many of these studies have been used to develop worldwide regulatory noise guidelines, such as those of the WHO,[104] which have proposed nighttime noise levels primarily focused on preventing sleep disturbance.

Because sound and its components are the potential health hazards associated with living near wind turbines, an assessment of other environmental noise studies can offer a valuable perspective in assessing health risks for people living near wind turbines. For example, one would not expect adverse health effects to occur at lower noise levels if the same effects do not occur at higher noise levels. In the studies of other environmental noise sources, noise levels have been considerably higher than those associated with wind turbines. Noise differences as broad as 15 dBA (eg, 55 dBA in highways vs 40 dBA from wind turbines) have been regularly reported.[147] In settings where anthropogenic changes are perceived, indirect effects such as annoyance have been reported, and these must also be considered in the evaluation of health effects.

We now attempt to address three fundamental questions posed at the beginning of this review related to potential health implications of wind turbines.

Is there available scientific evidence to conclude that wind turbines adversely affect human health? If so, what are the circumstances associated with such effects and how might they be prevented?

The epidemiological and experimental literature provides no convincing or consistent evidence that wind turbine noise is associated with any well-defined disease outcome. What is suggested by this literature, however, is that varying proportions of people residing near wind turbine facilities report annoyance with the turbines or turbine noise. It has been suggested by some authors of these studies that this annoyance may contribute to sleep disruption and/or stress and, therefore, lead to other health consequences. This self-reported annoyance, however, has not been reported consistently and, when observed, arises from cross-sectional surveys that inherently cannot discern whether the wind turbine noise emissions play any direct causal role. Beyond these methodological limitations, such results have been associated with other mediating factors (including personality and attitudinal characteristics), reverse causation (ie, disturbed sleep or the presence of a headache increases the perception of and association with wind turbine noise), and personal incentives (whether economic benefit is available for living near the turbines).

There are no available cohort or longitudinal studies that can more definitively address the question about causal links between wind turbine operations and adverse health effects. Nevertheless, results from cross-sectional and experimental studies, as well as studies of other environmental noise sources, can provide valuable information in assessing risk. On the basis of the published cross-sectional epidemiological studies, "annoyance" is the main outcome measure that has been raised in the context of living in the vicinity of wind turbines. Whether annoyance is an adverse health effect, however, is disputable. "Annoyance" is not listed in the International Classification of Diseases (10th edition), although it has been suggested by some that annoyance may lead to stress and to other health consequences, such as sleep disturbance. This proposed mechanism, however, has not been demonstrated in studies using methods capable of elucidating such pathways.

The authors of this review are aware of the Internet sites and non–peer-reviewed reports, in which some people have described symptoms that they attribute to living near wind turbines. The quality of this information, however, is severely limited such that reasonable assessments cannot be made about direct causal links between the wind turbines and symptoms reported. For example, inviting only people who feel they have symptoms because of wind turbines to participate in surveys and asking people to remember events in the past in the context of a current concern (ie, postturbine installation) introduce selection and recall biases, respectively. Such major biases compromise the reliability of the information as used in any rigorous causality assessment. Nonetheless, consistent associations have been reported between annoyance, sleep disturbance, and altered QOL among some people living near wind turbines. It is not possible to properly evaluate causal links of these claims in the absence of a thorough medical assessment, proper noise studies, and a valid study approach. The symptoms reported tend to be nonspecific and associated with various other illnesses. Personality factors, including self-assessed noise sensitivity, attitudes toward wind energy, and nocebo-like reactions, may play a role in the reporting of these symptoms. In the absence of thorough medical evaluations that include a characterization of the noise exposure and a diagnostic medical evaluation, confirmation that the symptoms are due to living near wind turbines cannot be made with any reliability. In fact, the use of a proposed case definition that seemed in a journal not indexed by PubMed can lead to misleading and incorrect assessments of people's health, if performed in the absence of a thorough diagnostic evaluation.[143] We recommend that people who suspect that they have symptoms from living near wind turbines undergo a thorough medical evaluation to identify all potential causes of and contributors to the symptoms. Attributing symptoms to living near wind turbines in the absence of a comprehensive medical evaluation is not medically appropriate. It is in the person's best interest to be properly evaluated to ensure that recognized and treatable illnesses are recognized.

Available scientific evidence does not provide support for any bona fide–specific illness arising out of living in the vicinity of wind turbines. Nonetheless, it seems that an array of factors contribute to some proportion of those living in proximity to wind turbines, reporting some degree of annoyance. The effect of prolonged annoyance—regardless of its source or causes—may have other health consequences, such as increasing stress; however, this cannot be demonstrated with the existing scientific literature on annoyance associated with wind turbine noise or visibility.

Is there available scientific evidence to conclude that psychological stress, annoyance, and sleep disturbance can occur as a result of living in proximity to wind turbines? Do these effects lead to adverse health effects? If so, what are the circumstances associated with such effects and how might they be prevented?

Available research is not suitable for assessing causality because the major epidemiological studies conducted to date have been cross-sectional, data from which do not allow the evaluation of the temporal relationship between any observed correlated factors.

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Cross-sectional studies, despite their inherent limitations in assessing causal links, however, have consistently shown that some people living near wind turbines are more likely to report annoyance than those living farther away. These same studies have also shown that a person's likelihood of reporting annoyance is strongly related to their attitudes toward wind turbines, the visual aspect of the turbines, and whether they obtain economic benefit from the turbines. Our review suggests that these other risk factors play a more significant role than noise from wind turbines in people reporting annoyance.

The effect of annoyance on a person's health is likely to vary considerably, based on various factors. To minimize these reactions, solutions may include informative discussions with area residents before developing plans for a wind farm along with open communications of plans and a trusted approach to responding to questions and resolving noise-related complaints.

Is there evidence to suggest that specific aspects of wind turbine sound such as infrasound and low-frequency sound have unique potential health effects not associated with other sources of environmental noise?

Both infrasound and low-frequency sound have been raised as possibly unique health hazards associated with wind turbine operations. There is no scientific evidence, however, including results from field measurements of wind turbine–related noise and experimental studies in which people have been purposely exposed to infrasound, to support this hypothesis. Measurements of low-frequency sound, infrasound, tonal sound emission, and amplitude-modulated sound show that infrasound is emitted by wind turbines, but that the levels at customary distances to homes are well below audibility thresholds, even at residences where people have reported symptoms that they attribute to wind turbines. These levels of infrasound—as close as 300 m from the turbines—are not audible. Moreover, experimental studies of people exposed to much higher levels of infrasound than levels measured near wind turbines have not indicated adverse health effects. Because infrasound is associated more with vibratory effects than high-frequency sound, it has been suggested that the vibration from infrasound may be contributing to certain physical sensations described by some people living near wind turbines. These sensations are difficult to reconcile in light of field studies that indicated that infrasound at distances more than 300 m for a wind turbine meet international standards for preventing rattling and other potential vibratory effects.[14]

Areas for Further Inquiry

In light of the limitations of available studies for drawing definitive conclusions and the need to address health-related concerns associated with wind turbines raised by some nearby residents, each author discussed potential areas of further inquiry to address current data gaps. These recommendations primarily address exposure characterization, health endpoints, and the type of epidemiological study most likely to lead to informative results regarding potential health effects associated with living near wind turbines.

Noise From Wind Turbines

As with any potential occupational or environmental hazard, further efforts at exposure characterization, that is, noise and its components such as infrasound and low-frequency sound, would be valuable. Ideally, uniform equipment and standardized methods of measurement can be used to enable comparison with results from published studies and evaluate adherence to public policy guidelines.

Efforts directed at evaluating models used to predict noise levels from wind turbines—in contrast to actual measured noise levels—would be valuable and may be helpful in informing and reassuring residents involved in public discussions related to the development of wind energy projects. Efforts at fine tuning noise models for accuracy to real-world situations can be reassuring to public health officials charged with evaluating potential health effects of noise. The development and the use of reliable and portable noise measuring devices to address components of noise near residences and evaluating symptoms and compliance with noise guidelines would be valuable.

Epidemiology

Prospective cohort studies would be most informative for identifying potential health effects of exposure to wind turbine noise before and after wind turbines are installed and operating. Ideally, substantially large populations would be evaluated for baseline health status, and subsequently part of the population would become exposed to wind turbines and part would remain unexposed, as in an area where large wind turbine farms are proposed or planned. The value of such studies is in the avoidance of several forms of bias such as recall bias, where study participants might, relying on recall, under- or overreport risk factors or diseases that occurred sometime in the past. As has been noted by several authors, the level of attention given the topic of wind turbines and possible health effects in the news and the Internet makes it difficult to study any population truly "blinded" to the hypotheses being evaluated. The main advantage of prospective cohort studies with a pre- and post–wind turbine component is the direct ability to compare changes in disease and health status among individuals subsequently exposed to wind turbine noise with those among similar groups of people not exposed. These conditions are not readily approximated by any other study approach. A similar but more complex approach could include populations about to become exposed to other anthropogenic stimuli, such as highways, railroads, commercial centers, or other power generation sources.

We note that additional cross-sectional studies may not be capable of contributing meaningfully and in fact might reinforce biases already seen in many cross-sectional studies and surveys.

Sound and Its Components

Several types of efforts can be undertaken to test hypotheses proposed about inaudible sound being a risk for causing adverse health effects. It would be simple, at least conceptually, to expose blinded subjects to inaudible sounds, especially in the infrasound range, to determine whether they could detect the sounds or whether they developed any unpleasant symptoms. Ideally, these studies would use infrasound levels that are close to hearing thresholds and comparable with real-world wind turbine levels at residential distances. Crichton et al[137,149] have begun such studies, finding that subjects could not detect any difference between infrasound and sham "exposures." The infrasound stimulus used, however, was only 40 dB at 5 Hz, more than 60 dB lower than hearing threshold and lower than levels measured at some residences near wind turbines.

The possibility of adverse effects from inaudible sound could also be tested in humans or animals in long-term studies. To date, there seem to be no reports of adverse effects in people exposed to wind turbine noise that they could never hear (such reports would require careful controls), nor are any relevant animal studies known to the authors of this review.

Controlled human exposure studies have been used to gain insight into the effects of exposure to LFN from wind turbines. Human volunteers are exposed for a short amount of time under defined conditions, sometimes following various forms of preconditioning, and different response metrics evaluated. Most of these studies addressed wind turbine noise annoyance but no direct health indicator; however, one study addressed visual reaction to the color of wind turbines in pictures,[73] and another evaluated physical symptoms in response to wind turbine noise.[137,149]

Efforts to document a potential effect of infrasound on health have been unsuccessful, including searches for responses to sound from cochlear type II afferent neurons or responses to inaudible

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airborne sound from the vestibular system. But in other cases, the relevant experiments (can inaudible sound cause endolymphatic hydrops?) seem not to have been conducted to date. This seemingly improbable hypothesis, however, could be tested in guinea pigs, which reliably develops endolymphatic hydrops in response to other experimental interventions.

Psychological Factors

This review has demonstrated that a complex combination of noise and personal factors contributes to some people reporting annoyance in the context of living near wind turbines. Further efforts at characterizing and understanding these issues can be directed to improvements in measurement of sound perception, data analysis, and conceptualization.

We suggest improvements in the quality and standardization of measurement for important constructs like noise sensitivity and noise annoyance across studies. We also suggest eliminating the use of single-item "measures" for primary outcomes.

Data analysis should ideally include effect size measures in all studies to supplement the significance testing (some significant differences are small when sample sizes are large). This will help improve the comparability of findings across studies.

Integrate noise sensitivity, noise annoyance, and QOL into a broader more comprehensive theory of personality or psychological functioning, such as the widely accepted five-factor model of personality.

SUMMARY

1. Measurements of low-frequency sound, infrasound, tonal sound emission, and amplitude-modulated sound show that infrasound is emitted by wind turbines. The levels of infrasound at customary distances to homes are typically well below audibility thresholds.
2. No cohort or case–control studies were located in this updated review of the peer-reviewed literature. Nevertheless, among the cross-sectional studies of better quality, no clear or consistent association is seen between wind turbine noise and any reported disease or other indicator of harm to human health.
3. Components of wind turbine sound, including infrasound and low-frequency sound, have not been shown to present unique health risks to people living near wind turbines.
4. Annoyance associated with living near wind turbines is a complex phenomenon related to personal factors. Noise from turbines plays a minor role in comparison with other factors in leading people to report annoyance in the context of wind turbines.

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Wind Turbine Health Impact Study:

Report of Independent Expert Panel

January 2012

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The Panel Charge

The Expert Panel was given the following charge by the Massachusetts Department of Environmental Protection (MassDEP) and Massachusetts Department of Public Health (MDPH):

1. Identify and characterize attributes of concern (e.g., noise, infrasound, vibration, and light flicker) and identify any scientifically documented or potential connection between health impacts associated with wind energy turbines located on land or coastal tidelands that can impact land-based human receptors.
2. Evaluate and discuss information from peer-reviewed scientific studies, other reports, popular media, and public comments received by the MassDEP and/or in response to the *Environmental Monitor Notice* and/or by the MDPH on the nature and type of health complaints commonly reported by individuals who reside near existing wind farms.
3. Assess the magnitude and frequency of any potential impacts and risks to human health associated with the design and operation of wind energy turbines based on existing data.
4. For the attributes of concern, identify documented best practices that could reduce potential human health impacts. Include examples of such best practices (design, operation, maintenance, and management from published articles). The best practices could be used to inform public policy decisions by state, local, or regional governments concerning the siting of turbines.
5. Issue a report within 3 months of the evaluation, summarizing its findings.

   To meet its charge, the Panel conducted a literature review and met as a group a total of three times. In addition, calls were also held with Panel members to further clarify points of discussion.

Executive Summary

The Massachusetts Department of Environmental Protection (MassDEP) in collaboration with the Massachusetts Department of Public Health (MDPH) convened a panel of independent experts to identify any documented or potential health impacts of risks that may be associated with exposure to wind turbines, and, specifically, to facilitate discussion of wind turbines and public health based on scientific findings.

While the Commonwealth of Massachusetts has goals for increasing the use of wind energy from the current 40 MW to 2000 MW by the year 2020, MassDEP recognizes there are questions and concerns arising from harnessing wind energy. The scope of the Panel's effort was focused on health impacts of wind turbines *per se*. The panel was *not* charged with considering any possible benefits of avoiding adverse effects of other energy sources such as coal, oil, and natural gas as a result of switching to energy from wind turbines.

Currently, "regulation" of wind turbines is done at the local level through local boards of health and zoning boards. Some members of the public have raised concerns that wind turbines may have health impacts related to noise, infrasound, vibrations, or shadow flickering generated by the turbines. The goal of the Panel's evaluation and report is to provide a review of the science that explores these concerns and provides useful information to MassDEP and MDPH and to local agencies that are often asked to respond to such concerns. The Panel consists of seven individuals with backgrounds in public health, epidemiology, toxicology, neurology and sleep medicine, neuroscience, and mechanical engineering. All of the Panel members are considered independent experts from academic institutions.

In conducting their evaluation, the Panel conducted an extensive literature review of the scientific literature as well as other reports, popular media, and the public comments received by the MassDEP.

ES 1. Panel Charge

1. Identify and characterize attributes of concern (e.g., noise, infrasound, vibration, and light flicker) and identify any scientifically documented or potential connection between health impacts associated with wind turbines located on land or coastal tidelands that can impact land-based human receptors.
2. Evaluate and discuss information from peer reviewed scientific studies, other reports, popular media, and public comments received by the MassDEP and/or in response to the *Environmental Monitor Notice* and/or by the MDPH on the nature and type of health complaints commonly reported by individuals who reside near existing wind farms.
3. Assess the magnitude and frequency of any potential impacts and risks to human health associated with the design and operation of wind energy turbines based on existing data.
4. For the attributes of concern, identify documented best practices that could reduce potential human health impacts. Include examples of such best practices (design, operation, maintenance, and management from published articles). The best practices could be used to inform public policy decisions by state, local, or regional governments concerning the siting of turbines.
5. Issue a report within 3 months of the evaluation, summarizing its findings.

ES 2. Process

To meet its charge, the Panel conducted an extensive literature review and met as a group a total of three times. In addition, calls were also held with Panel members to further clarify points of discussion. An independent facilitator supported the Panel's deliberations. Each Panel member provided written text based on the literature reviews and analyses. Draft versions of the report were reviewed by each Panel member and the Panel reached consensus for the final text and its findings.

ES 3. Report Introduction and Description

Many countries have turned to wind power as a clean energy source because it relies on the wind, which is indefinitely renewable; it is generated "locally," thereby providing a measure of energy independence; and it produces no carbon dioxide emissions when operating. There is interest in pursuing wind energy both on-land and offshore. For this report, however, the focus is on land-based installations and all comments are focused on this technology. Land-based

wind turbines currently range from 100 kW to 3 MW (3000 kW). In Massachusetts, the largest turbine is currently 1.8 MW.

The development of modern wind turbines has been an evolutionary design process, applying optimization at many levels. An overview of the characteristics of wind turbines, noise, and vibration is presented in Chapter 2 of the report. Acoustic and seismic measurements of noise and vibration from wind turbines provide a context for comparing measurements from epidemiological studies and for claims purported to be due to emissions from wind turbines. Appendices provide detailed descriptions and equations that allow a more in-depth understanding of wind energy, the structure of the turbines, wind turbine aerodynamics, installation, energy production, shadow flicker, ice throws, wind turbine noise, noise propagation, infrasound, and stall vs. pitch controlled turbines.

Extensive literature searches and reviews were conducted to identify studies that specifically evaluate human population responses to turbines, as well as population and individual responses to the three primary characteristics or attributes of wind turbine operation: noise, vibration, and flicker. An emphasis of the Panel's efforts was to examine the biological plausibility or basis for health effects of turbines (noise, vibration, and flicker). Beyond traditional forms of scientific publications, the Panel also took great care to review other non-peer reviewed materials regarding the potential for health effects including information related to "Wind Turbine Syndrome" and provides a rigorous analysis as to whether there is scientific basis for it. Since the most commonly reported complaint by people living near turbines is sleep disruption, the Panel provides a robust review of the relationship between noise, vibration, and annoyance as well as sleep disturbance from noises and the potential impacts of the resulting sleep deprivation.

In assessing the state of the evidence for health effects of wind turbines, the Panel followed accepted scientific principles and relied on several different types of studies. It considered human studies of the most important or primary value. These were either human epidemiological studies specifically relating to exposure to wind turbines or, where specific exposures resulting from wind turbines could be defined, the panel also considered human experimental data. Animal studies are critical to exploring biological plausibility and understanding potential biological mechanisms of different exposures, and for providing information about possible health effects when experimental research in humans is not ethically

or practically possible. As such, this literature was also reviewed with respect to wind turbine exposures. The non-peer reviewed material was considered part of the weight of evidence. In all cases, data quality was considered; at times, some studies were rejected because of lack of rigor or the interpretations were inconsistent with the scientific evidence.

ES 4. Findings

The findings in Chapter 4 are repeated here.

Based on the detailed review of the scientific literature and other available reports and consideration of the strength of scientific evidence, the Panel presents findings relative to three factors associated with the operation of wind turbines: noise and vibration, shadow flicker, and ice throw. The findings that follow address specifics in each of these three areas.

ES 4.1 Noise

ES 4.1.a Production of Noise and Vibration by Wind Turbines

1. Wind turbines can produce unwanted sound (referred to as noise) during operation. The nature of the sound depends on the design of the wind turbine. Propagation of the sound is primarily a function of distance, but it can also be affected by the placement of the turbine, surrounding terrain, and atmospheric conditions.
    a. Upwind and downwind turbines have different sound characteristics, primarily due to the interaction of the blades with the zone of reduced wind speed behind the tower in the case of downwind turbines.
    b. Stall regulated and pitch controlled turbines exhibit differences in their dependence of noise generation on the wind speed
    c. Propagation of sound is affected by refraction of sound due to temperature gradients, reflection from hillsides, and atmospheric absorption. Propagation effects have been shown to lead to different experiences of noise by neighbors.
    d. The audible, amplitude-modulated noise from wind turbines (“whooshing”) is perceived to increase in intensity at night (and sometimes becomes more of a “thumping”) due to multiple effects: i) a stable atmosphere will have larger wind gradients, ii) a stable atmosphere may refract the sound downwards instead of upwards, iii) the ambient noise near the ground is lower both because of the stable atmosphere and because human generated noise is often lower at night.

2. The sound power level of a typical modern utility scale wind turbine is on the order of 103 dB(A), but can be somewhat higher or lower depending on the details of the design and the rated power of the turbine. The perceived sound decreases rapidly with the distance from the wind turbines. Typically, at distances larger than 400 m, sound pressure levels for modern wind turbines are less than 40 dB(A), which is below the level associated with annoyance in the epidemiological studies reviewed.
3. Infrasound refers to vibrations with frequencies below 20 Hz. Infrasound at amplitudes over 100–110 dB can be heard and felt. Research has shown that vibrations below these amplitudes are not felt. The highest infrasound levels that have been measured near turbines and reported in the literature near turbines are under 90 dB at 5 Hz and lower at higher frequencies for locations as close as 100 m.
4. Infrasound from wind turbines is not related to nor does it cause a "continuous whooshing."
5. Pressure waves at any frequency (audible or infrasonic) can cause vibration in another structure or substance. In order for vibration to occur, the amplitude (height) of the wave has to be high enough, and only structures or substances that have the ability to receive the wave (resonant frequency) will vibrate.

ES 4.1.b Health Impacts of Noise and Vibration

1. Most epidemiologic literature on human response to wind turbines relates to self-reported "annoyance," and this response appears to be a function of some combination of the sound itself, the sight of the turbine, and attitude towards the wind turbine project.
   a. There is limited epidemiologic evidence suggesting an association between exposure to wind turbines and annoyance.
   b. There is insufficient epidemiologic evidence to determine whether there is an association between noise from wind turbines and annoyance independent from the effects of seeing a wind turbine and vice versa.

2. There is limited evidence from epidemiologic studies suggesting an association between noise from wind turbines and sleep disruption. In other words, it is possible that noise from some wind turbines can cause sleep disruption.
3. A very loud wind turbine could cause disrupted sleep, particularly in vulnerable populations, at a certain distance, while a very quiet wind turbine would not likely disrupt even the lightest of sleepers at that same distance. But there is not enough evidence to provide particular sound-pressure thresholds at which wind turbines cause sleep disruption. Further study would provide these levels.
4. Whether annoyance from wind turbines leads to sleep issues or stress has not been sufficiently quantified. While not based on evidence of wind turbines, there is evidence that sleep disruption can adversely affect mood, cognitive functioning, and overall sense of health and well-being.
5. There is insufficient evidence that the noise from wind turbines is *directly (i.e., independent from an effect on annoyance or sleep)* causing health problems or disease.
6. Claims that infrasound from wind turbines directly impacts the vestibular system have not been demonstrated scientifically. Available evidence shows that the infrasound levels near wind turbines cannot impact the vestibular system.
    a. The measured levels of infrasound produced by modern upwind wind turbines at distances as close as 68 m are well below that required for non-auditory perception (feeling of vibration in parts of the body, pressure in the chest, etc.).
    b. If infrasound couples into structures, then people inside the structure could feel a vibration. Such structural vibrations have been shown in other applications to lead to feelings of uneasiness and general annoyance. The measurements have shown no evidence of such coupling from modern upwind turbines.
    c. Seismic (ground-carried) measurements recorded near wind turbines and wind turbine farms are unlikely to couple into structures.
    d. A possible coupling mechanism between infrasound and the vestibular system (via the Outer Hair Cells (OHC) in the inner ear) has been proposed but is not yet fully understood or sufficiently explained. Levels of infrasound near wind turbines have been shown to be high enough to be sensed by the OHC. However, evidence does not

exist to demonstrate the influence of wind turbine-generated infrasound on vestibular-mediated effects in the brain.

e. Limited evidence from rodent (rat) laboratory studies identifies short-lived biochemical alterations in cardiac and brain cells in response to short exposures to emissions at 16 Hz and 130 dB. These levels exceed measured infrasound levels from modern turbines by over 35 dB.

7. There is no evidence for a set of health effects, from exposure to wind turbines that could be characterized as a "Wind Turbine Syndrome."
8. The strongest epidemiological study suggests that there is not an association between noise from wind turbines and measures of psychological distress or mental health problems. There were two smaller, weaker, studies: one did note an association, one did not. Therefore, we conclude the weight of the evidence suggests no association between noise from wind turbines and measures of psychological distress or mental health problems**.**
9. None of the limited epidemiological evidence reviewed suggests an association between noise from wind turbines and pain and stiffness, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and headache/migraine.

ES 4.2 Shadow Flicker

ES 4.2.a Production of Shadow Flicker

Shadow flicker results from the passage of the blades of a rotating wind turbine between the sun and the observer.

1. The occurrence of shadow flicker depends on the location of the observer relative to the turbine and the time of day and year.
2. Frequencies of shadow flicker elicited from turbines is proportional to the rotational speed of the rotor times the number of blades and is generally between 0.5 and 1.1 Hz for typical larger turbines.
3. Shadow flicker is only present at distances of less than 1400 m from the turbine.

ES 4.2.b Health Impacts of Shadow Flicker

1. Scientific evidence suggests that shadow flicker does not pose a risk for eliciting seizures as a result of photic stimulation.

2. There is limited scientific evidence of an association between annoyance from prolonged shadow flicker (exceeding 30 minutes per day) and potential transitory cognitive and physical health effects.

ES 4.3 Ice Throw

ES 4.3.a Production of Ice Throw

Ice can fall or be thrown from a wind turbine during or after an event when ice forms or accumulates on the blades.

1. The distance that a piece of ice may travel from the turbine is a function of the wind speed, the operating conditions, and the shape of the ice.
2. In most cases, ice falls within a distance from the turbine equal to the tower height, and in any case, very seldom does the distance exceed twice the total height of the turbine (tower height plus blade length).

ES 4.3.b Health Impacts of Ice Throw

1. There is sufficient evidence that falling ice is physically harmful and measures should be taken to ensure that the public is not likely to encounter such ice.

ES 4.4 Other Considerations

In addition to the specific findings stated above for noise and vibration, shadow flicker and ice throw, the Panel concludes the following:

1. Effective public participation in and direct benefits from wind energy projects (such as receiving electricity from the neighboring wind turbines) have been shown to result in less annoyance in general and better public acceptance overall.

ES 5. Best Practices Regarding Human Health Effects of Wind Turbines

The best practices presented in Chapter 5 are repeated here.

Broadly speaking, the term “best practice” refers to policies, guidelines, or recommendations that have been developed for a specific situation. Implicit in the term is that the practice is based on the best information available at the time of its institution. A best practice may be refined as more information and studies become available. The panel recognizes that in countries which are dependent on wind energy and are protective of public health, best practices have been developed and adopted.

In some cases, the weight of evidence for a specific practice is stronger than it is in other cases. Accordingly, best practice* may be categorized in terms of the evidence available, as follows:

Descriptions of Three Best Practice Categories

Category	Name	Description
1	Research Validated Best Practice	A program, activity, or strategy that has the highest degree of proven effectiveness supported by objective and comprehensive research and evaluation.
2	Field Tested Best Practice	A program, activity, or strategy that has been shown to work effectively and produce successful outcomes and is supported to some degree by subjective and objective data sources.
3	Promising Practice	A program, activity, or strategy that has worked within one organization and shows promise during its early stages for becoming a best practice with long-term sustainable impact. A promising practice must have some objective basis for claiming effectiveness and must have the potential for replication among other organizations.

**These categories are based on those suggested in "Identifying and Promoting Promising Practices." Federal Register, Vol. 68. No 131. 131. July 2003.*
www.acf.hhs.gov/programs/ccf/about_ccf/gbk_pdf/pp_gbk.pdf

ES 5.1 Noise

Evidence regarding wind turbine noise and human health is limited. There is limited evidence of an association between wind turbine noise and both annoyance and sleep disruption, depending on the sound pressure level at the location of concern. However, there are no research-based sound pressure levels that correspond to human responses to noise. A number of countries that have more experience with wind energy and are protective of public health have developed guidelines to minimize the possible adverse effects of noise. These guidelines consider time of day, land use, and ambient wind speed. The table below summarizes the guidelines of Germany (in the categories of industrial, commercial and villages) and Denmark (in the categories of sparsely populated and residential). The sound levels shown in the table are

for nighttime and are assumed to be taken immediately outside of the residence or building of concern. In addition, the World Health Organization recommends a maximum nighttime sound pressure level of 40 dB(A) in residential areas. Recommended setbacks corresponding to these values may be calculated by software such as WindPro or similar software. Such calculations are normally to be done as part of feasibility studies. The Panel considers the guidelines shown below to be Promising Practices (Category 3) but to embody some aspects of Field Tested Best Practices (Category 2) as well.

Promising Practices for Nighttime Sound Pressure Levels by Land Use Type

Land Use	**Sound Pressure Level, dB(A) Nighttime Limits**
Industrial	70
Commercial	50
Villages, mixed usage	45
Sparsely populated areas, 8 m/s wind*	44
Sparsely populated areas, 6 m/s wind*	42
Residential areas, 8 m/s wind*	39
Residential areas, 6 m/s wind*	37

**measured at 10 m above ground, outside of residence or location of concern*

The time period over which these noise limits are measured or calculated also makes a difference. For instance, the often-cited World Health Organization recommended nighttime noise cap of 40 dB(A) is averaged over one year (and does not refer specifically to wind turbine noise). Denmark's noise limits in the table above are calculated over a 10-minute period. These limits are in line with the noise levels that the epidemiological studies connect with insignificant reports of annoyance.

The Panel recommends that noise limits such as those presented in the table above be included as part of a statewide policy regarding new wind turbine installations. In addition, suitable ranges and procedures for cases when the noise levels may be greater than those values should also be considered. The considerations should take into account trade-offs between

environmental and health impacts of different energy sources, national and state goals for energy independence, potential extent of impacts, etc.

The Panel also recommends that those involved in a wind turbine purchase become familiar with the noise specifications for the turbine and factors that affect noise production and noise control. Stall and pitch regulated turbines have different noise characteristics, especially in high winds. For certain turbines, it is possible to decrease noise at night through suitable control measures (e.g., reducing the rotational speed of the rotor). If noise control measures are to be considered, the wind turbine manufacturer must be able to demonstrate that such control is possible.

The Panel recommends an ongoing program of monitoring and evaluating the sound produced by wind turbines that are installed in the Commonwealth. IEC 61400-11 provides the standard for making noise measurements of wind turbines (International Electrotechnical Commission, 2002). In general, more comprehensive assessment of wind turbine noise in populated areas is recommended. These assessments should be done with reference to the broader ongoing research in wind turbine noise production and its effects, which is taking place internationally. Such assessments would be useful for refining siting guidelines and for developing best practices of a higher category. Closer investigation near homes where outdoor measurements show A and C weighting differences of greater than 15 dB is recommended.

ES 5.2 Shadow Flicker

Based on the scientific evidence and field experience related to shadow flicker, Germany has adopted guidelines that specify the following:

1. Shadow flicker should be calculated based on the astronomical maximum values (i.e., not considering the effect of cloud cover, etc.).
2. Commercial software such as WindPro or similar software may be used for these calculations. Such calculations should be done as part of feasibility studies for new wind turbines.
3. Shadow flicker should not occur more than 30 minutes per day and not more than 30 hours per year at the point of concern (e.g., residences).
4. Shadow flicker can be kept to acceptable levels either by setback or by control of the wind turbine. In the latter case, the wind turbine manufacturer must be able to demonstrate that such control is possible.

The guidelines summarized above may be considered to be a Field Tested Best Practice (Category 2). Additional studies could be performed, specifically regarding the number of hours per year that shadow flicker should be allowed, that would allow them to be placed in Research Validated (Category 1) Best Practices.

ES 5.3 Ice Throw

Ice falling from a wind turbine could pose a danger to human health. It is also clear that the danger is limited to those times when icing occurs and is limited to relatively close proximity to the wind turbine. Accordingly, the following should be considered Category 1 Best Practices.

1. In areas where icing events are possible, warnings should be posted so that no one passes underneath a wind turbine during an icing event and until the ice has been shed.
2. Activities in the vicinity of a wind turbine should be restricted during and immediately after icing events in consideration of the following two limits (in meters).

For a turbine that may not have ice control measures, it may be assumed that ice could fall within the following limit:

$$x_{\max,\, throw} = 1.5\left(2R + H\right)$$

Where: R = rotor radius (m), H = hub height (m)

For ice falling from a stationary turbine, the following limit should be used:

$$x_{\max,\, fall} = U\left(R + H\right)/15$$

Where: U = maximum likely wind speed (m/s)

The choice of maximum likely wind speed should be the expected one-year return maximum, found in accordance to the International Electrotechnical Commission's design standard for wind turbines, IEC 61400-1.

Danger from falling ice may also be limited by ice control measures. If ice control measures are to be considered, the wind turbine manufacturer must be able to demonstrate that such control is possible.

ES 5.4 Public Participation/Annoyance

There is some evidence of an association between participation, economic or otherwise, in a wind turbine project and the annoyance (or lack thereof) that affected individuals may express. Accordingly, measures taken to directly involve residents who live in close proximity

to a wind turbine project may also serve to reduce the level of annoyance. Such measures may be considered to be a Promising Practice (Category 3).

ES 5.5 Regulations/Incentives/Public Education

The evidence indicates that in those parts of the world where there are a significant number of wind turbines in relatively close proximity to where people live, there is a close coupling between the development of guidelines, provision of incentives, and educating the public. The Panel suggests that the public be engaged through such strategies as education, incentives for community-owned wind developments, compensations to those experiencing documented loss of property values, comprehensive setback guidelines, and public education related to renewable energy. These multi-faceted approaches may be considered to be a Promising Practice (Category 3).

ENERGY AND POLICY INSTITUTE

Wind Health Impacts Dismissed in Court

BY MIKE BARNARD, SENIOR FELLOW ON WIND ENERGY

Edited by Gabe Elsner and Matt Kasper

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Foreword

New technology has a long history of attracting small networks of people who believe that rapidly proliferating inventions are silently eroding people's health. Electric light and railway travel were early villains to those who saw such inventions as Mephistophelean artifice. On September 24, 1889, the British Medical Journal carried a report that the newly popular telephone could causes "telephone tinnitus" claiming that victims "suffered from nervous excitability, with buzzing noises in the ear, giddiness, and neuralgic pains".

In the 125 years since, televisions, electric blankets, microwave ovens, computer screens, mobile phones, and transmission towers, and most recently, Wi-Fi and smart meters are examples of technology where claims of potential calamitous consequences of biblical plague proportions have been made.

The idea that wind turbines might be harmful to people's health began to attract minor attention around 2002, when claims made in unpublished "research" by a British general practitioner was covered by a few news outlets. The 2009 publication of a self-published vanity press book, "Wind Turbine Syndrome", by a pediatrician, Nina Pierpont, acted like petrol thrown on a fire of anxiety in some communities where activists were doing their utmost to urge people to interpret common health problems found in any community as being caused by sub-audible infrasound emitted by wind turbines.

Since that time, a small number of anti-wind activists operating mainly in parts of Australia, Canada, Ireland, United Kingdom, and the United States made this their *cause celebre*. In some cases, these groups have documented links to climate change denial groups and fossil fuel interests. Without exception, they see themselves as contemporary Galileos, fearlessly holding aloft the truth in the face of doctrinaire denial from the scientific establishment, which has now published 21 evidence reviews since 2003, which dismiss claims of direct health effects from wind turbines. The groups point knowingly to the historical denials of harm by the asbestos and tobacco industries convinced that the pernicious "Big Wind" industry is reading from the very same playbook.

Legal action has emerged as a favored tactic of these groups. In this report, Mike Barnard, Senior Fellow at the Energy and Policy Institute, catalogues the outcomes of 49 attempts by wind farm opponents to use the courts or tribunals to stop developments. In all but one case, these attempts have failed. Barnard also profiles 16 alleged expert witnesses called by these opponents.

These forlorn actions will have caused many residents who were swept along by the emotive claims of often visiting anti wind activists, and then joined the legal actions to have lost substantial sums in legal costs.

Anyone curious about the track record, quality of the expertise enlisted, and arguments advanced by these litigants will find this publication indispensible. But, its most important readership will be anyone tempted to repeat this folly. Barnard's summaries and the links provided to the cases are more than sobering.

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University of Sydney

Introduction

Global installed capacity of wind energy has increased 568 percent over the past ten years. This significant acceleration of wind energy development, while benefiting the health of humans and the environment, has drawn opposition. Individuals and local groups who are opposed to the construction of wind turbines have claimed health impacts in order to prevent the wind farms from being built. But, these efforts have not been successful, and for good reason: wind farms do not cause health problems.

Therefore, government entities at the local and state level, and developers should not expect to be held liable for health issues blamed upon wind energy, as the cases have been rejected time and time again.

This Energy and Policy Institute report assesses legal cases in five English-speaking countries pertaining to wind energy. The intent is to provide clarity in assessing potential legal liability, and to identify the weaknesses of evidence and expertise that are common in health-related suits against wind farms.

This report was designed as a resource for wind energy legal defense teams and expert witnesses in preparing for any future court proceedings. The precedence of past legal cases shows health claims against wind energy have not been substantiated in court.

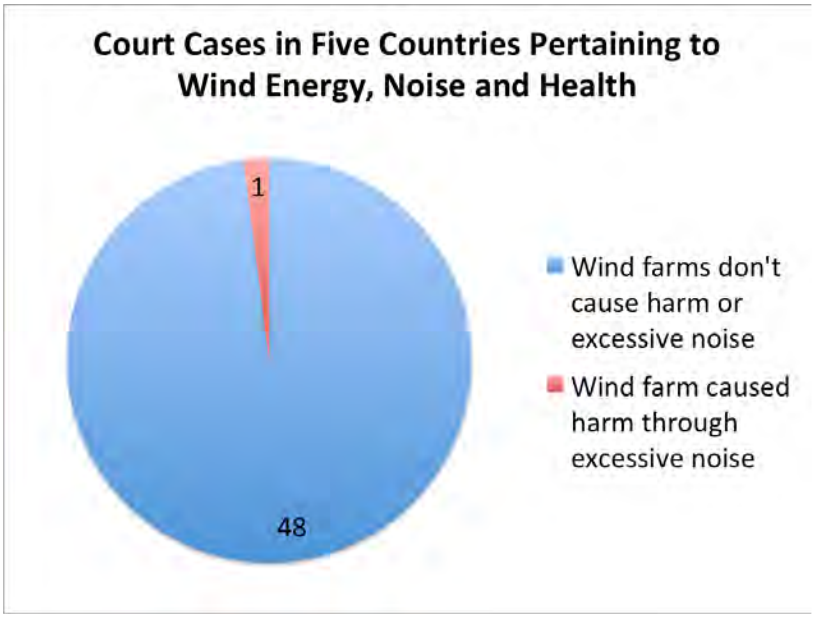
Acknowledgments

This report would not have been possible without the ongoing support and guidance of a worldwide collection of experts in wind farm noise and health with whom I communicate frequently and are regularly asked to provide evidence in different courts regarding wind farm noise and health concerns. These include but are not limited to Professor Simon Chapman, Dr. Geoffrey Leventhall, Professor Emerita Cecilia Barnes, Christophe Delaire, Fiona Crichton, Dr. David Perry, Loren Knopper, Dr. Norm Broner and Richard Mackie. Further, wind energy experts such as Paul Gipe, Malcolm Hamilton, Ketan Joshi, and Roger Short have provided excellent insights as I have been assessing wind energy court proceedings and health concerns worldwide.

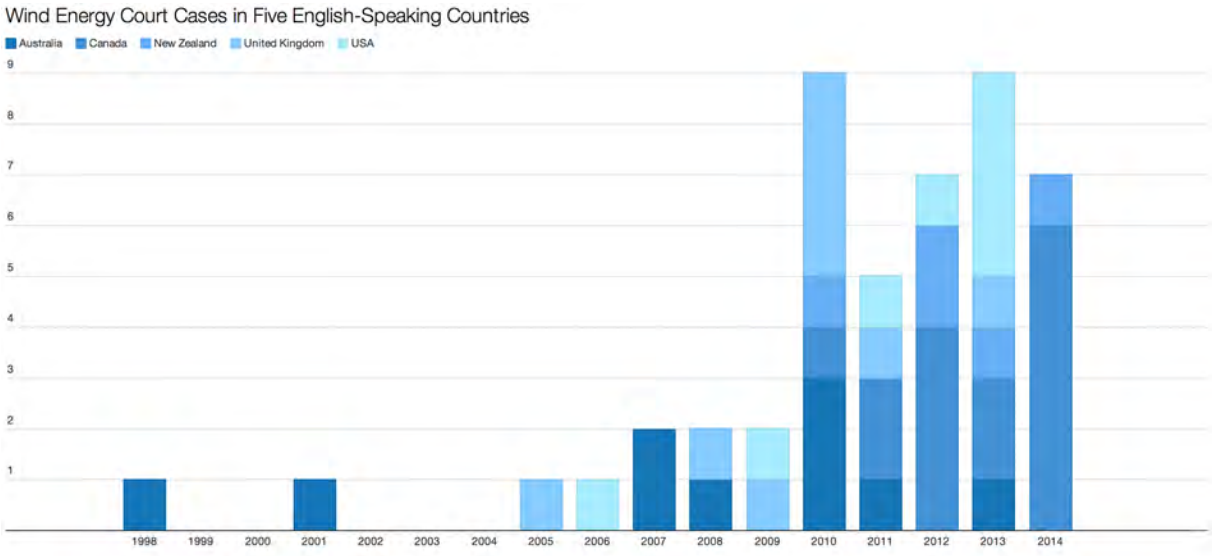
Of course, the leadership and staff at the Energy and Policy Institute must be thanked, especially Gabe Elsner and Matt Kasper, without whom this report would not exist.

Overview of Court Cases

Since 1998, 49 hearings have been held under rules of legal evidence in at least five English-speaking countries and four types of courts regarding wind energy, noise, and health. Forty-eight assessed the evidence and found no potential for harm to human health. The sole outlier is an instructive but unique case.



To find the decisions, I searched legal databases of environmental, utility, civil, and higher courts in Canada, New Zealand, the United States of America (USA), the United Kingdom, and Australia. In the USA, this required state-by-state searches. I also searched anti-wind campaign sites for the Waubra Foundation and the US National Wind Watch for cited cases. I requested information from contacts in the wind industry and wind advocacy organizations as well. While well over 150 potential decisions were found and assessed and 49 found that pertained to noise and health, this does not mean that every single case has been identified. Courts in Denmark, Germany and the Netherlands have also found no connection between wind turbines and health issues per reports, but the records are not in English.



Court cases jumped dramatically after Dr. Nina Pierpont, the pediatrician wife of an anti-wind activist, self-published a book alleging health risks from wind turbines based on phone interviews with a self-selected and very small number of people who blamed them for commonly experienced symptoms.

Canada is the center of wind farm health-related court challenges, with 17 separate hearings for its 7.8 GW of wind energy capacity and a population of 35 million.

This is mostly due to Ontario, with 14 Environmental Review Tribunals (ERT) testing the evidence and the relative experts, as well as two higher court cases. The mechanism of the ERT was specifically referenced in the Renewable Energy Act to provide recourse related to specific wind farms, and it's being heavily exercised.

The province of Alberta has seen two significant cases in its Alberta Utility Commission court, and the province of Saskatchewan saw a single civil suit related to wind energy and health.

All Canadian courts found that wind farms would not and do not cause health impacts with proper setbacks in place.

Next up is Australia with 10 cases over its 2.7 GW of capacity and a population of 23 million.

The state of Victoria appears to be the Ontario of Australia, with seven civil suits.

The states of South Australia and New South Wales saw three cases in their environment and resource courts.

All Australian cases found that wind farms would not cause health impacts with proper setbacks in place.

The United Kingdom has seen the next highest numbers of cases, with nine hearings over its more than 10 GW of wind energy capacity and a population of 63 million.

The county of Devon saw the most cases, with three bringing evidence related to wind energy, noise, and health. Denbighshire had two cases, and various other counties and Scotland each had one case.

All United Kingdom cases found that wind farms would not cause health impacts with proper setbacks in place.

In one outlier case in the UK, a wind farm complied fully with the noise standards, but the Inspector charged with assessing the wind farm siting felt the combination of wind farms in the area would cause discernible noise on more evenings in households than was acceptable; this was upheld as being within the authority of the Inspector upon appeal.

The United States saw eight court cases in total that pertained to wind energy, noise, and health concerns over its 61 GW of wind energy capacity and population of 314 million people.

States in the northeast represented five of the eight court cases with the other three taking place in the central United States.

Seven cases found no harm from wind energy with the proper setbacks currently in place.

The USA has the only case where a wind farm was considered to have caused harm. This case was brought by a single family near a pair of wind farms erected on the municipal wastewater treatment plant by the town of Falmouth, Massachusetts. The judgment includes the statement that dental harm occurred, along with other types of medical ailments. This single small wind farm is referenced worldwide by anti-wind advocacy groups as if it is representative of wind health court cases instead of a unique outlier.

New Zealand, somewhat surprisingly given its size, managed five environmental and civil hearings over wind energy, noise and health over 0.6 GW of wind energy capacity and population of 4.4 million people.

Only one case in New Zealand went against a wind farm, the Te Rere Hau wind project, and that was only because noise was greater than anticipated, not because the wind noise was above standards or harmful to human health. This case is widely misrepresented and selectively quoted by anti-wind campaigning organizations such as the Waubra Foundation and National Wind Watch.

The raw numbers become startling when compared to both capacity and population of each of the countries. The United States has, by far, the lowest incidence of litigation and legal procedures, while New Zealand has the most. This is over a very small number of cases, so not much can be inferred from this, but it is interesting nonetheless. All numbers in the table are as of July 2014. There is roughly one court case per 10 million people and for every two GW of wind energy to date for English speaking countries.

	Cases	GW of Wind Energy Capacity	Cases per GW	Populace (millions)	Cases per million populace
Canada	17	7.8	2.18	35.0	0.49
Australia	10	2.7	3.70	23.0	0.43
United Kingdom	9	10.0	0.90	63.0	0.14
United States	8	61.0	0.13	314.0	0.03
New Zealand	5	0.6	8.33	4.4	1.14
Summary	**49**	**82.1**	**0.60**	**439.4**	**0.11**

An important conclusion can be reached in reviewing the various courts' decisions - many people put forward as expert witnesses bring a great deal of passion against wind energy, but very little expertise. See the section on inexpert 'experts' brought against wind energy in court cases for additional details.

A complete list of cases that have been assessed and analyzed for this report can be found in the Addendum.

The Challenge of Inexpert Experts

Over the past several years, anti-wind campaigners without credentials or experience related to wind energy and its effects on humans have attempted to elevate themselves into the role of expert witnesses in civil suits, Environmental Review Tribunals (ERT) in Canada, and Environmental Resources and Development (ERD) proceedings in Australia. This report singles out 16 individuals based on the courts' dismissal of their expertise or evidence.

Name	Specialty
1. Sarah Laurie	Formerly a general practitioner of medicine, but no longer allowed to use any medical title following an ethics investigation
2. Dr. Nina Pierpont	Pediatrician
3. Dr. Robert McMurtry	Orthopedic Surgeon
4. Dr. Michael Nissenbaum	Radiologist
5. Dr. Carl Phillips	Scientific Director of The Consumer Advocates for Smoke-Free Alternatives Association; Advisor to Society for Wind Vigilance
6. Dr. Daniel Shepherd	Psychoacoustics
7. Bill Palmer	Professional Engineer
8. Mike McCann	Property Appraiser
9. Ben Lansink	Property Appraiser
10. Richard James	Acoustician
11. Eric Erhard	Professional Engineer
12. Les Huson	Master of Science, Structural Engineering
13. Dr. Colin Hansen	Emeritus Professor; Mechanical Engineer
14. Dr. Adrian Upton	Emeritus Professor, Neurology
15. Debbie Shubat	Registered Nurse
16. Lori Davies	Masters Degree of Social Work

These 16 individuals and the lawyers who attempt to bring them into court have overstated the relevance of their credentials, as well as the depth and breadth of their expertise. Their claim that wind farms impact human health is dismissed in nearly every hearing, or given little weight by the judges. Additionally, these non-experts often introduce hundreds of pages of what they term evidence, but the vast majority of the documents are poorly constructed opinion pieces by other non-experts. The documents can usually be found on websites maintained by wind energy opponents. They often attempt to introduce "studies" that are methodologically and statistically weak. This evidence takes significant time and court resources to assess and discount; therefore, the trend to disqualify their evidence early in legal proceedings is important.

1. Sarah Laurie

In 2011, Ms. Sarah Laurie attempted to testify at an ERD proceeding in Australia. During the testimony, Laurie admitted she was not an expert in the subject matter she was called to testify on, and qualified experts in additional testimony discredited her submission. But, this did not stop Laurie from submitting future testimony.

In a judgment released in December 2013 from an ERT in Ontario, Bovaird v. Director, Ministry of the Environment, Laurie's evidence was rejected almost entirely. The remaining evidence was deemed biased and of low reliability.

Five pages in the judgment devoted to Laurie's background determined:

1. Ms. Laurie is not a doctor and must stop referring to herself as one, as part of an agreement with the Australian Health Practitioner Regulation Agency (AHPRA), based on the outcome of an ethics complaint.
2. She is not licensed or permitted to diagnose patients because she is deregistered and non-practicing. However, she has continued to diagnose people.
3. Most of her planned testimony required her to diagnose patients.
4. Ms. Laurie has no training in research methodology and design.
5. Ms. Laurie is not a trained acoustician.
6. Ms. Laurie has not performed a comprehensive literature review related to wind farms.

In summary, the Ontario ERT considered her a biased witness, and gave less weight to the evidence she submitted.

Also in 2013, the Ontario ERT prohibited Laurie as an expert witness in a case regarding the Adelaide project proposed by NextEra Energy Resources. She was rejected as a witness very early in the proceedings, after she admitted that she could no longer call herself a doctor.

Months later, Laurie was allowed to testify in a hearing for the BullCreek Wind Project in Alberta, Canada. Despite her earlier admission, she portrayed herself as a doctor. However, the commission gave its opinion on her competence, skills, and testimony, stating:

> *Dr. Laurie's written evidence also included her interpretation and discussion of numerous published and unpublished epidemiological and acoustical reports and studies. In the Commission's view, Dr. Laurie lacks the necessary skills, experience and training to comment on the interpretation of epidemiologic studies or the interpretation of acoustical studies and reports. The Commission gave little weight to this aspect of Dr. Laurie's evidence.*

2. Dr. Nina Pierpont

Dr. Nina Pierpont was a long-term campaigner against wind farms near her home who conducted a minor and very poorly constructed health survey. This survey was the basis for her self-published book which coined the phrase, "wind turbine syndrome." This "syndrome" is widely referenced by people campaigning against wind turbines. Pierpont claims that wind turbines cause tinnitus, dizziness, heart-palpitations, nausea, tingling, and loss of sleep, among several other symptoms. However, the book is deeply flawed.

Pierpont interviewed 23 people by phone. They were chosen by advertising through anti-wind groups that blamed wind farms for their health issues. Pierpont also accepted statements about an additional 15 household members without speaking to them and did not assess health histories of the participants outside of verbal statements by people surveyed. She hypothesized a connection of infrasound and created 60 pages of charts, graphs, and tables, a level of statistical analysis far beyond anything supportable by the data. The symptoms she identified are very commonly found in the general populace.

There have been 22 literature reviews on wind turbine health and many point-specific

studies on wind turbine noise, vibration, infrasound, and shadow flicker, conducted by public health doctors and scientists, acousticians, epidemiologists, and related specialists. The studies considered Pierpont's book along with other published literature. In every case, they found that her work was lacking in credibility. Recent major reviews have been conducted in Ontario, Massachusetts, Oregon and Australia with the same results.

In October of 2013, Pierpont attempted to gain expert witness status at the Adelaide ERT wind farm hearing in Ontario. She wrote:

> *I will attempt to teach the representatives of NextEra and the Ontario Ministry of the Environment, as well as the members of the Tribunal, enough about brain and ear physiology and pathophysiology, population-level studies in free-living organisms, and medical interviewing that they can understand the wind turbine-associated health issues.*

Pierpont has no expertise from education or experience in "brain and ear physiology and pathophysiology, population-level studies in free-living organisms, and medical interviewing." Her evidence included her self-published book, which along with her testimony, was dismissed.

3. Dr. Robert McMurtry

Dr. Robert McMurtry is an orthopedic surgeon, founder of the anti-wind Society for Wind Vigilance, and long-serving Board Member of the anti-wind Association to Protect Prince Edward County (APPEC). McMurtry is also the owner of a rural retirement residence in Prince Edward County Ontario near proposed wind farms, and initiated, with his wife, a $2.5 million lawsuit against a nearby wind farm.

McMurtry's main contribution to anti-wind literature is a draft case definition of impact from wind farms that he published in *Bulletin of Science, Technology, and Society*. The publication has been de-indexed since 1995, a sign that indexing services regard the journal to have fallen below acceptable academic standards.

There is little evidence of peer review of any substantive nature in the set of anti-wind articles published in the special edition in which McMurtry's case definition was published.

In 2011, McMurtry participated in a challenge to the regulated minimum 550 meter setbacks from wind turbines to homes in Ontario Superior Court case, Hanna v. Ontario (Attorney General). McMurtry asserted that there was medical uncertainty and risk associated with the setback that had not been considered in establishing it. During the case, McMurtry was forced to admit that none of the evidence he brought to bear was new:

> *The applicant acknowledges that virtually all of the information relied on by Dr. McMurtry to form his assessment regarding the health impacts of industrial wind turbines was known to the ministry at the time the regulation was being considered.*

In 2013, McMurtry testified in the Ostrander Point-related tribunal, Alliance to Protect Prince Edward County v. Director, Ministry of the Environment in 2013. While permitted to testify, his case definition was dismissed as evidence:

> *With respect to the proposed Case Definition of AHE/IWTs, the Tribunal finds that it is a work in progress. It is preliminary attempt to explain symptoms that appear to be suffered by people with whom Dr. McMurtry is familiar, who live in the environs of wind turbines. Dr. McMurtry's case definition has admittedly not been validated; thus there is currently no grouping of symptoms recognized by the medical profession as caused by wind turbines.*

The Ostrander tribunal ruled against the wind farm based on impacts to the endangered Blanding's Turtle, that was overturned on appeal, and as of July 2014, the approval is stayed pending another appeal.

In the Bovaird v. Director, Ministry of the Environment Tribunal, McMurtry attempted to testify about concerns well outside the boundary's the ERT provided for him. The ERT found that McMurtry's affidavit discussing Ontario's energy mix and generating capacity were "clearly not within Dr. McMurtry's area of expertise." The Tribunal did not admit the testimony as evidence, and wrote that the testimony he was qualified to provide was of no value.

A more recent Tribunal found:

> *Dr. McMurtry failed to provide any support for his proposition that a non-trivial percentage of persons who both live and work near turbines will be highly annoyed. … Nor is there any evidence about how any of the subjective influencing factors that affected the response of residential dwellers…*

Furthermore, the Director of the Ministry of the Environment questioned McMurtry's judgment regarding wind turbines:

> *The Director questions Dr. McMurtry's objectivity and is concerned that he is advocating on behalf of the Appellant. The Director submits that his evidence is largely improper reply evidence, and should be regarded with extreme caution and given little weight.*

In February 2014, a Superior Court appeal of the Ostrander Point ERT decision was released. Judge Nordheimer, in rejecting appeals related to human health, had this to say about McMurtry's testimony:

> *[122] It is not sufficient for the purposes of relying on a novel scientific theory to simply conclude that the theory may be correct. In that situation, the theory will not have crossed the threshold of reliability for the purpose of establishing the necessary causal link between the activity in issue and the consequences said to arise from that activity. Rather, the party attempting to rely on a novel scientific theory must first establish threshold reliability before the fact finder may consider it.*
>
> *[123] The Supreme Court of Canada has set out four factors to be considered in determining whether threshold reliability is met. In R. v. J.-L.J., [2000] 2 S.C.R. 600, the four factors were identified, at para. 33, as:*
>
> > *(i) whether the theory or technique can be and has been tested;*
> > *(ii) whether the theory or technique has been subjected to peer review and publication;*
> > *(iii) the known or potential rate of error or the existence of standards; and,*
> > *(iv) whether the theory or technique used has been generally accepted.*
>
> *[124] Viewed from the medical perspective, and that is the perspective that is relevant in this case since harm to human health is being asserted, the expert evidence offered by APPEC, through Dr. McMurtry, failed when tested against any of these factors. Dr. McMurtry's theory has not been tested, it has not been medically peer reviewed, it is not known what the error rate might be and the theory has not been generally accepted.*

If Dr. McMurtry were not a long-serving and respected member of the Ontario medical establishment -- which I fully respect as well — there is little doubt that he would not be granted expert status in virtually any Ontario court due to obvious issues with bias and lack of actual expertise.

4. Dr. Michael Nissenbaum

Dr. Michael Nissenbaum is a radiologist, not a researcher, acoustician, epidemiologist or public health expert. Additionally, he is a member of the Advisory Board of the anti-wind group, Society for Wind Vigilance.

Nissenbaum performed a "health survey" of people near two wind farms in Maine, where he lives. The survey was deeply flawed because of the insignificant sample size and the low response rate. Health surveys require at least a 50 percent response rate to be considered useful. The survey identified that it was assessing wind energy noise and health problems, and the questions were leading and pushed desired responses upon the respondents.

McMurtry attempted to enter Nissenbaum's study into evidence in the 2013 Bovaird v. Director, Ministry of the Environment ERT in Ontario. The evidence was dismissed.

Nissenbaum has also published a report regarding wind energy and health in a credible peer-reviewed and indexed journal *Noise and Health*. However, two separate critiques of his paper were published in the same journal pointing out significant errors and erroneous conclusions.

In 2010, Nissenbaum attempted to serve as an expert witness in an ERT in Saskatchewan, Canada. The case was over the Red Lily Wind Energy Corporation proposed wind farm near the townships of Martin and Moosomin, Saskatchewan. The Tribunal wrote:

> *Dr. Nissenbaum is a medical doctor. He has not had any specialized training in any of the issues I have identified that are required in order to provide opinion evidence to support the injunction application. Although he has some limited experience as a result of his survey on the Mars Hill project, the nature, size and methodology used in that survey is of no value to the current application…*
>
> *Dr. Nissenbaum has obtained a great deal of information on this subject, but information is not knowledge, and Dr. Nissenbaum does not have the type of knowledge referred to in the court cases that makes him an expert in any of the areas that I have identified as necessary.*

In 2011, Nissenbaum tried again in another Ontario ERT. The Tribunal took the position that most witnesses brought forward would be allowed to testify, but the areas where they were explicitly considered experts would be listed, and their testimony considered in that

light. The Tribunal allowed Nissenbaum to give his expert opinion in the areas of diagnostic imaging.

However, his entire testimony was outside of his area of expertise. The ERT found:

> *The Nissenbaum Study and Dr. Aramini's application of it, raise enough questions about the Study to suggest that its results do not meet the legal threshold that wind turbine noise will cause serious harm to human health at the 550 m setback at the Kent Breeze Project. These questions include issues pertaining to: study design, statistical analysis, causation analysis and the transferability of the findings, given the difference in wind turbine design and in the physical lay-out and topography between the study site and that at the Kent-Breeze Project.*

Most recently, Nissenbaum's study was presented as evidence at the Bull Creek Wind Project siting in Alberta in 2013. The final judgment stated:

> *The Commission does not find the Nissenbaum study to be compelling evidence that wind turbine noise below 40 dBA will cause sleep disturbance or health effects. The Commission considers that the study's use of noise data from publicly available records and from a single day of measurements is not a sufficient basis for drawing conclusions about a dose-response relationship for wind turbine noise.*

In February of 2014, the Australian National Health and Medical Research Council reviewed Nissenbaum's study as part of an exhaustive review of wind turbines and health concern studies. The council classified the quality of the study as "poor" because of the clear bias Nissenbaum demonstrated.

5. Dr. Carl V. Phillips

Before Dr. Carl V. Phillips was being presented as an expert witness at wind development planning hearings, he was a fixture in courtrooms related to tobacco health suits. His ties to the tobacco industry and acceptance of tobacco funding ultimately caused the end of his academic career. Phillips then set up his own research foundation and has come out against peer-reviewed research, specifically regarding wind turbines.

Phillips published a paper related to epidemiology and wind energy in the un-indexed *Bulletin of Science, Technology and Society.* He is also a

member of the Science Advisory Group of the Society for Wind Vigilance.

In late 2013, Phillips testified in an Alberta court related to the Bull Creek Wind Project. The final judgment stated:

> *The Commission carefully reviewed the evidence provided by Dr. Phillips and finds that his prediction that three per cent of area residents will experience severe health effects and approximately 50 per cent will experience some health effects is not supported by the evidence for the following reasons.*
>
> *First, Dr. Phillips provided little rationale for his predictions regarding the number of people who would experience health effects from the project. Dr. Phillips stated he based his prediction that 50 per cent of nearby residents will experience health effects on "things like the Nissenbaum study" but did not elaborate further…*
>
> *Second, Dr. Phillips confirmed that his conclusions were not based upon any particular adverse event reports and, in fact, he had not reviewed any adverse event reports in the preparation of his written evidence…*
>
> *Third, Dr. Phillips confirmed that the data he looked at was not organized in a systematic way and that he did not break down the data to determine a dose-response relationship between wind turbine operation and the symptoms he described. In other words, he did not correlate the prevalence or the intensity of the constellation of symptoms he identified with the sound levels at the persons' residences or the distance between the person experiencing the symptoms and the turbine(s) in question.*
>
> *Fourth, Dr. Phillips conceded that he had not specifically defined the population upon which his conclusions were based upon…*

6. Dr. Daniel Shepherd

Dr. Daniel Shepherd received his PhD in psychoacoustics and is a Senior Lecturer at the Auckland University of Technology. He performed a study on the Makara Valley wind farm in New Zealand. It had a very small sample size of 39 participants, and a non-equivalent control group that found no self-reported variance in health or illness. Nonetheless, Shepherd asserted that setbacks of wind farms greater than two kilometers (1.2 miles) were required in hilly terrain. As with others on this list, he is a member of the Society for Wind Vigilance.

Shepherd has been granted expert witness status at several hearings in Canada and New Zealand. However, his testimony did not convince the review bodies that wind farms caused health problems, that setbacks should be changed, or that acoustics standards were inadequate.

And in 2011, he testified at a New Zealand Environment Court hearing for the Hurunui wind farm in Canterbury. Judge Melanie Harland, and Commissioners Marlene Oliver and Bruce Gollop wrote:

> *Dr. Shepherd referred to papers by Pierpont and Harry to support his theory that health effects can arise from turbine noise, but… Dr. Pierpont's work in this area has been criticized and should not be considered reliable.*

Shepherd tried again at an Ontario ERT pertaining to the Suncor's Chatham Kent wind farm in 2013. According to the Tribunal, Dr. Kenneth Mundt, based on his 5 years of application of epidemiological concepts to potential environmental harm, said:

> *Dr. Mundt asserted that Dr. Shepherd does not provide scientific evidence to support his claims regarding stress related health effects caused by noise induced sleep deficits and annoyance. He stated that many of the references that Dr. Shepherd includes in his report are not peer reviewed published scientific research. Further, the interpretation of the results cited by Dr. Shepherd is severely limited due to the methodological issues in the designs and methods used in conducting these studies... Dr. Mundt stated that Dr. Shepherd did not explain how he identified and assessed the literature for quality and comparability, and therefore, it cannot be determined whether his conclusions are based on a thorough review of the literature or only a few selected studies... Dr. Mundt questioned the data presented in Dr. Shepherd's evidence, as he included no description of methodology for collecting or analyzing his data. Dr. Mundt stated that Dr. Shepherd fails to define "degradation of amenity" in his report and provides no scientific evidence to support his opinion that degradation of amenity at the Kent Breeze Wind Farms will cause serious adverse health effects.*

Shepherd's testimony did not convince the judge in the Tribunal that wind turbines cause health problems.

7. Bill Palmer

Mr. Bill Palmer has a Bachelor of Science in Electrical Engineering, is a Professional Engineer, and worked for Bruce Nuclear, a Canadian nuclear power generating station, as a shift supervisor and trainer. He took early retirement to oppose wind energy development, and has been attempting to introduce evidence at Canadian ERTs with little success.

In a 2011, the Ontario Erickson ERT discussed his qualifications at length. In the end, the Tribunal said it did not matter if he were rendered expert status as his evidence was unconvincing and irrelevant compared to that of the acknowledged experts in his areas of concern:

It is quite clear that, even if the Tribunal were to accord Mr. Palmer's evidence full status as expert evidence, there is no question that the Tribunal heard much more detailed and convincing evidence on the issues raised by Mr. Palmer from the other relevant witnesses...

> *In sum, even if the Tribunal were to treat Mr. Palmer's evidence as expert evidence, the best that can be said of it is that Mr. Palmer provided evidence of some "risks" of harm that fall well below the statutory test applicable to this proceeding.*

In October of 2013, Palmer attempted to serve as an expert witness again, this time at the Adelaide ERT in Ontario. This time he was limited in his testimony only to his areas of expertise, which ultimately eliminated most of his submitted evidence and testimony.

Palmer has often ignored the constraints. In this case, the Tribunal judgment stated:

> *…in his evidence, Mr. Palmer baldly states that shadow flicker will occur and states his opinion that it will distract drivers. However, Mr. Palmer was not qualified to give opinion evidence on the impact of shadow flicker.*
>
> *Mr. Palmer does not provide any explanation, nor was he qualified to give opinion evidence, on how a driver might respond to such flicker, and, to the extent it caused distraction, whether the nature of the distraction could interfere with a driver's ability to safely drive the vehicle.*
>
> *In light of the deficiency in Mr. Palmer's assessment and the un-contradicted opinion evidence of Mr. Dokouzian, the Tribunal finds that the Appellants have not established that shadow flicker will cause serious harm to drivers on Highway 402.*
>
> *In summary, due to the numerous deficiencies in Mr. Palmer's assessment, and limitations respecting the evidence adduced in response to Mr. Palmer's evidence, the Tribunal finds that it has received insufficient evidence to make any definitive findings regarding the probability that blade throw, tower collapse, and damage resulting from a tower fire, would cause harm to human health.*

Despite being told at least twice that he is not an expert and that his evidence failed every test of relevance applied to it, Palmer attempted to gain expert status on multiple subjects at the ERT in Ontario regarding the Arnow wind project.

> *Mr. Palmer gave evidence as a participant. He asked to be qualified to give opinion evidence as a professional engineer with expertise on acoustics and several matters related to public safety. Following submissions from the parties, the Tribunal qualified Mr. Palmer as a professional engineer with expertise in public safety risks due to turbine failure and some experience in the acoustics of wind turbines. The Tribunal directed Mr. Palmer to confine his testimony to public safety and acoustical assessment and to not speak to topics outside his area of qualification, such as health effects or shadow flicker along highways.*

His evidence created conflicts, with actual experts pointing out numerous faults in the topics he was allowed to present to the Tribunal:

> *It was his [Mr. Dokouzian] position that Mr. Palmer selectively referred to a few statements in that study and used them out of context, while ignoring the overall conclusion of the study, that is, that the wakes of adjacent turbines did not increase the level of noise from a wind farm.*
>
> *Mr. Dokouzian repeated the approach he used to calculate maximum sound power levels and took issue with Mr. Palmer's approach. He criticized him for "cherry-picking" the highest sound power level at each octave band, adding them and adjusting them to reach a figure that is higher than the maximum possible sound power level. He stated that such an approach is not indicated in any standard or guideline and is not justified with wind turbines. He explained that the specifications Mr. Palmer found for the Siemens models that were used in a wind farm in Nova Scotia were specifications from the 2009 models of those turbines, whereas for the Project, he used the specifications from the 2013 models, which indicate evolution in the certainty of their measurements, and somewhat lower sound levels as a result.*
>
> *Mr. Coulson commented on the noise measurements undertaken by Mr. Palmer that were reported in the papers he has presented at conferences. Mr. Coulson identified a concern with the instrumentation used by Mr. Palmer as being not of high quality for acoustical measurements and having a large degree of noise associated with the equipment that Mr. Palmer did not account for. He also expressed concern about Mr. Palmer's lack of familiarity with the noise measurement standards and with some of the aspects of the locations he chose for carrying out his measurements.*
>
> *Mr. Palmer was questioned about the papers he has prepared and presented at*

conferences. These papers were largely based on noise measurements he carried out at existing wind farms in Ontario. He asserted that his measurements were conducted in accordance with international standards, but was unable to identify the particular standard to which they conform and was unable to state the confidence limits with his data, although he suggested it might be around +/- 1.5 dB.

Mr. Palmer identified his concern that the Project was within the minimum setback from 500 kV power lines established by Hydro One so that a turbine failure could lead to a failure in the electrical system corridor. When questioned, he admitted that he had never seen a Hydro One standard or technical guideline and did not know whether his concern was the basis for a setback between turbines and power lines.

Palmer has been accused of cherry-picking and using discredited data, using inaccurate instruments inappropriately, being unfamiliar with regulations, and not accepting the variance in amplitude modulation. Yet, he continues to attempt to testify against wind turbines. The Approval Holder noted:

Regarding the evidence of Mr. Palmer on the risk to public safety due to turbine collapse, blade failure, fire and ice throw, the Approval Holder submits that his evidence is unreliable, unscientific, provides no meaningful analysis of risk and is misleading.

8. Mike McCann

Mr. Mike McCann is a real estate appraiser from Chicago. He's a regular in anti-wind circles, constantly attempting to push his flawed case studies and statistical analyses to prove that wind farms cause property value harm. At present, he has conducted two small studies covering 81 property transactions, compared to the 10 major studies in North America and Europe covering 1.3 million property transactions. Using appropriate statistical methods, these studies show no damage to property values.

McCann was slated as a witness for the appellant at an ERT in Ontario regarding the Adelaide project in October 2013. He was slated to testify about habitat destruction from wind farms, a clear divergence from any expertise he might have. He was rejected as a witness before testifying:

Ben Lansink and Michael McCann, whom the Tribunal has ruled cannot testify in this proceeding.

9. Ben Lansink

Mr. Ben Lansink, like Mike McCann, is a property appraiser. Similarly to McCann, Lansink has a case study covering only 12 property transactions, which he claims, in the face of overwhelming evidence to the contrary, proves property value harm. For this, he is regularly cited and encouraged by anti-wind campaigners.

Also like McCann, Lansink was slated to testify on habitat destruction at an ERT regarding the Adelaide project in October 2013. Lansink was rejected as a witness before testifying:

Ben Lansink and Michael McCann, whom the Tribunal has ruled cannot testify in this proceeding.

10. Rick James

Mr. Rick James is a professional acoustician. When testifying or advocating against wind turbines, James has difficulty staying within the bounds of his actual expertise.

When he has attempted to testify at wind farm related lawsuits in the United States, his testimony has been demonstrated to be lacking in substance, his noise studies lacking in any rigor and his credentials and experience unrelated to measuring wind-related noise. He was slated to appear at the ERT in Ontario regarding the Adelaide project and attempted to introduce testimony unrelated to acoustics. The ERT restricted his testimony strictly to matters of acoustics, eliminating most of his submission.

James also gave testimony at an ERT pertaining to the K2 Wind Huron County project. The council for the Ministry of the Environment noted:

> *The Approval Holder states that Mr. James has a bias against wind development and purported to give evidence beyond the scope of his expertise, and in so doing breached his obligations as an independent expert and the Tribunal's Practice Direction for Technical and Opinion Evidence ("Practice Direction for Opinion Evidence").*

The ERT agreed:

> *[T]he Appellants had not established that the threshold to establish a deprivation or "serious psychological or physical harm" had been met.*

James also appeared at the Armow ERT, and his testimony included areas outside of his expertise and made substantial errors:

> *The Tribunal considered the submissions of the parties on this issue and qualified Mr. James to given opinion evidence on matters related to acoustics and noise control engineering and wind turbines. The Tribunal excluded from its consideration evidence provided by Mr. James concerning the health effects of wind turbines, and epidemiology.*
>
> *He is a member of the Institute of Noise Control Engineers ("INCE"), but is not certified by the INCE as an acoustical engineer, nor is he a registered professional engineer in any jurisdiction.*
>
> *He did concede that he is not an epidemiologist and was not aware of the limits of the Waterloo study identified by Dr. Bigelow. He also agreed that he did not include reference to epidemiological studies that came to differing conclusions in his witness statement.*

James is not a certified acoustician or a registered professional engineer, but identifies himself and sells his services as both. He is prone to hyperbole while on the witness stand. He attempts to make erroneous claims despite having been corrected in exactly the same type of ERT proceedings previously. Yet, he continues to put himself forward as an expert.

11. Eric Erhard

Mr. Eric Erhard is a retired professional engineer who lives near a proposed wind farm in southern Ontario. He attempted to gain accreditation as an expert witness related to application of ISO standards on noise modeling to wind turbine noise specifically. He based his experience with the relevant ISO standard in his professional career for the Chatham-Kent Wind Action Inc. v. Director, Ministry of the Environment tribunal.

The Tribunal was not convinced and stated:

> *In reviewing Mr. Erhard's submissions, the Tribunal finds that he does not have the specialized education, training or experience to qualify him to give expert evidence with respect to the application of ISO 9613-2 to noise from wind turbines. Mr. Erhard did not specifically submit that he had any specialized education or training with respect to the application of ISO 9613-2 to noise from wind turbines. Instead, he relied on his experience working for a company as an engineer and working with ISO 9613-2.*
>
> *For the purpose of giving expert opinion evidence, the Tribunal finds that Mr. Erhard has failed to establish that the ISO standard can be applied to evaluate a project as complex as an industrial wind turbine facility by someone who does not have specialized knowledge and experience for this type of application.*

The Tribunal agreed that he could speak to the ISO standard, but as he had no expertise on its application to wind farms and presented no evidence that his concerns related to application of the standard would have any impact on health, it was irrelevant testimony.

12. Les Huson

Mr. Les Huson is an engineer and acoustician running a small acoustics consultancy, L Huson and Associates Pty Ltd. This business is a member of the Association of Australian Acoustical Consultants. He regularly submits material against wind turbines and gains expert standing based on his credentials.

However, his testimonies often are disputed once submitted. During an ERD proceeding in 2011 related to the Allendale East wind farm, Huson attempted to bring evidence based on an alternative noise model to the standard ISO model more generally used. He then misused the model he was presenting and was forced to backpedal under cross-examination:

> *In cross-examination, Mr. Huson… was forced to concede that the authors of the ENM model had issued a Technical Note stating that the ENM had propensity to predict unusually high noise levels for this type of noise. In the Technical Note, the authors recommended that, when using the ENM, a correction needed to be applied to wind speeds for sources having a height greater than 10 meters.*
>
> *In the circumstances, we reject the evidence of Mr. Huson.*

Huson also submitted a lengthy set of material to the Victoria VCAT case related to the Cherry Tree wind farm in 2013. His testimony was referenced in the decision as being accepted over objections, and the Cherry Tree decision ruled in

favor of the wind farm. Huson gave evidence the same year at an Environment Court in New Zealand for the Hurunui wind farm proposal. Again he attempted to discredit an existing standard with inadequate understanding of it, and his evidence was dismissed.

Huson has a several year history of submitting material that does not bear scrutiny, yet continues to be brought forward as an expert witness.

13. Dr. Colin Hansen

Professor Hansen is an Emeritus Professor of the School of Mechanical Engineering at the University of Adelaide. He received his PhD in Mechanical Engineering.

In 2010, he testified in an ERD proceeding for a wind project:

Hansen gave evidence in the appellants' case. *Hansen is highly qualified and an expert acoustic engineer, but he has very little experience with wind farms. Professor Hansen's brief from the appellants was basically to provide a critique of Mr Turnbull's evidence and other information about the acoustic properties of the proposed wind farm. He was not, therefore, in a position to put a prediction of his own up against Mr Turnbull's. Professor Hansen was concerned that, at higher wind speeds, the wind may exceed Mr Turnbull's predictions. Part of the basis for this was a desire for proof beyond the manufacturer's assurance that the noise level would not increase at wind speeds over 12 m/s. No factual basis was provided for Professor Hansen's concern. Mr Knill's explanation of the manufacturer's assurance was provided in his statement at para 42:*

[…]

92. We accept Mr Knill and Mr Turnbull's evidence on this point.

Hansen continues to provide submissions to wind siting proposals.

14. Dr. Adrian Upton

Dr. Adrian Upton, Emeritus Professor of McMaster University, is a relatively new addition to the ranks of purported experts called against wind farms. Last year, he submitted testimony regarding the Bull Creek Wind Project. The judgment by the Alberta Utilities Commission stated:

> *In the Commission's view, Dr. Upton did not appear to have specialized knowledge or experience specifically with respect to wind turbines and their health effects (other than epilepsy). Dr. Upton appeared to be unfamiliar with the qualifications of some of the authors of the reports he relied upon in forming his opinion on the health impacts of wind turbines or whether the reports he referenced were published or peer reviewed. The Commission took this apparent unfamiliarity with the subject into account when it weighed Dr. Upton's evidence regarding the general health impacts of wind turbines on nearby residents.*

It's likely that courts will be seeing more of this Dr. Upton in the next couple of years, as he testifies on his actual area of expertise, agreeing that wind turbines will not cause epileptics any problems, but then proceeds to submit unsupported testimony in unfamiliar areas.

15. Debbie Shubat

Ms. Debbie Shubat is a Registered Nurse and teaches nursing at Sault College in Sault St. Marie in northern Ontario. As pictured, she has been protesting plans for a local wind farm near Bow Lake.

The Environmental Review Tribunal appeal related to the wind farm differed in their decision released July 9, 2014:

[28] Ms. Shubat asked to be qualified to give opinion evidence as an expert in public health nursing and the interactions between wind turbines and human and community health. She has a Master of Science in Nursing degree, and was qualified as an expert community health nurse in a previous REA appeal, Moseley v. Director (Ministry of the Environment), [2014] O.E.R.T.D. No. 23 ("Moseley"). The Approval Holder and Director opposed her qualification on the basis that her expertise does not extend to the impact of wind turbines on human health.

[29] The Tribunal declined to qualify Ms. Shubat as an expert, ruling that the subject matter of her expertise, that being nursing and community health nursing, does not qualify her to give expert opinion evidence on the impact of wind turbines on human health. As outlined by the Supreme Court of Canada in R. v Mohan, [1994] 2 S.C.R. 9 ("Mohan"), the field of expertise must be relevant to the issue to be decided, in order for the Tribunal to receive opinion evidence. The Tribunal reviewed Ms. Shubat's witness statement and found that all of the opinions she expressed were related to the impact of wind turbines on human health. She testified that any expertise she possesses in this regard comes from self-study. Ms. Shubat was clear that, as a nurse, she is not qualified to diagnose medical conditions and would not purport to do so. Ms. Shubat proceeded to give her evidence as a lay (fact) witness.

[30] A number of documents about the impact of wind turbines on human health were attached to Ms. Shubat's witness statement as documents that she wished to rely upon. However, as Ms. Shubat was found not to have the qualifications to interpret and explain them for the Tribunal, or to put them into context within the existing scientific debate around wind turbines and human health, the articles could not be accepted for the truth of their contents and were not admitted into evidence.

16. Lori Davies

Ms. Lori Davies is a registered social worker who operates a small therapy business after having held various formal positions in social work. As with Shubat, Davies attempted to gain accreditation as an expert witness in the Bow Lake ERT and was rejected as documented in their July 9, 2014 decision:

[34] Ms. Davies requested designation by the Tribunal as an expert in social work. Ms. Davies has a Masters Degree in social work and

considerable professional experience. The Approval Holder and Director had no issue with her professional qualifications as a social worker, but objected to the Tribunal qualifying her to give expert opinion evidence in the hearing on the basis that her qualification does not extend to the impacts of wind turbines on human health.

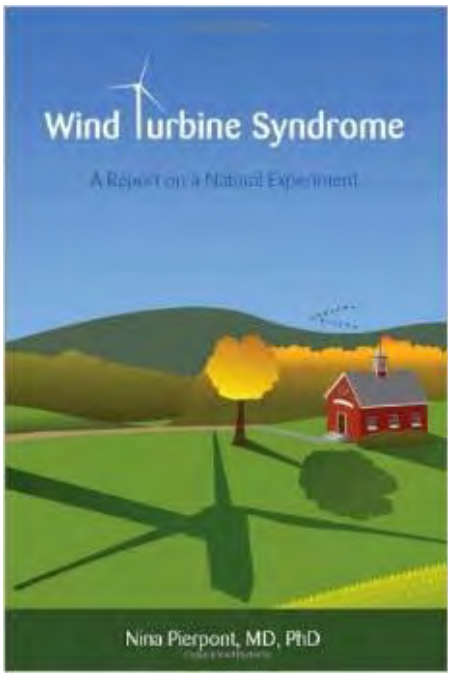
[35] The Tribunal ruled that Ms. Davies' expertise as a social worker is not sufficiently related to wind turbines and harm to human health to give the opinions she is purporting to give, and declined to designate her as an expert. In this respect the Tribunal relies on Mohan, as above. As with Ms. Shubat, the Tribunal also did not allow into evidence the documents Ms. Davies wished to rely on in forming her opinion, which were all outside of her area of expertise. Ms. Davies therefore gave her evidence as a lay witness.

Summary

At present, 16 individuals, with varying degrees of expertise, have attempted to gain status as expert witnesses related to negative impacts of wind turbines under rules of legal evidence. These individuals lacked expertise and substantial evidence as detailed by courts around the world. However, this has not prevented the testimony from being submitted. As more anti-wind experts continue to appear, often pushing the same material, we expect more testimony from anti-wind "experts" will be rejected. The trend to disqualify these witnesses early in wind energy court cases is necessary to avoid wasting further taxpayer resources.

Wind Health Expert Ethics Challenges

There are at least three former and current medical professionals who are leveraging no-longer-active or irrelevant medical credentials to lend weight to campaigns against wind energy, and are performing research without oversight. Medical ethics watchdogs are beginning to take note.



Perhaps the most prominent is Nina Pierpont, a pediatrician who sought to recruit anti-wind activists for a study via anti-wind groups who blamed wind farms for their health conditions. Pierpont interviewed 23 people by phone, accepted hearsay evidence on a further 15 people, and performed no direct examinations or medical histories. Yet, she self published a 294-page book. As a result, she coined a "new medical condition" called Wind Turbine Syndrome. Along with her husband, she presides over a website of the same name where dissenting opinions are not welcome, and comparisons of wind energy supporters to Hitler and Nazis are regular features.

In Canada, Carmen Krogh, retired pharmacist and member of the Advisory Group of the anti-wind energy campaigning organization, the Society for Wind Vigilance, regularly speaks to media and groups, and regularly submits to wind farm siting cases. She has been fighting a wind farm in their retirement community along with her husband. She also has published error-filled attacks against wind energy and turbines. Recently, Krogh presented a paper at the 5th Annual Wind Turbine Noise 2013 Conference, where she was corrected by an audience member for misrepresenting and misquoting others.

In Australia, Sarah Laurie is a former general practitioner who is now unregistered and the CEO of the Waubra Foundation, an anti-wind lobbyist group with strong fossil fuel ties. Ms. Laurie's ethics infractions have become the formal subject of complaints and ethics investigations.

A primary principle of medical ethics is "First, do no harm." An outcome of that principle

Image Courtesy of Independent Australia

is that medical professionals must take care when doing any research or asserting any health implications that they do not cause worse problems than they are researching. As such, any medical research, especially that involving direct contact with a study group, involves a medical ethics assessment by a group set up for that purpose.

Since 2009, a hypothesis for increasing health complaints near a subset of wind farms in English-speaking countries has been that they are caused by the nocebo effect, but "wind turbine syndrome" is in fact a psychogenic or communicated disease.

The nocebo effect, first named by WP Kennedy in 1961, is the negative side of the placebo effect. Instead of suggestions leading to positive health outcomes, suggestions lead to negative health outcomes. The nocebo effect causes health issues in psychogenic health hysterias such as "fan death," where people believe that a fan in a closed room chops oxygen molecules in two, causing them to be unable to breathe. The nocebo effect causes some side effects of medicine, creating a challenge for the ethical disclosure of potential side effects of medication. As a result, the nocebo effect is a confounding factor in clinical trials of medication and treatment techniques. Direct studies into the nocebo effect have been banned due to medical ethics concerns since roughly the 1970s.

Researchers are now assessing the nocebo and psychogenic hypotheses, finding strong evidence that they are the cause of the majority of complaints and are responsible for significant increases in numbers and severity of complaints. Professor Simon Chapman and a team of researchers at the Public Health Faculty of the University of Sydney of Australia found strong supporting evidence that the psychogenic hypothesis was the dominant factor in wind farm health complaints in a recently published study undergoing formal peer review and publication.

Ms. Fiona Crichton and along with researchers from the University of Auckland in New Zealand found strong supporting evidence for the nocebo effect being the cause of significantly increased numbers and severity of symptoms attributed to infrasound (noise below the frequency which humans can hear, typically zero to twenty Hertz).

Studies such as Crichton's that assess the nocebo effect are required to ensure that larger goals of the study are expected to have positive health outcomes, and that negative

impacts of the nocebo effect are monitored during the study and the study terminated if they become too severe. Further, study participants are informed after the study was over that the goal was to assess the nocebo effect and that symptoms that they experienced were not due to infrasound, following standard practice.

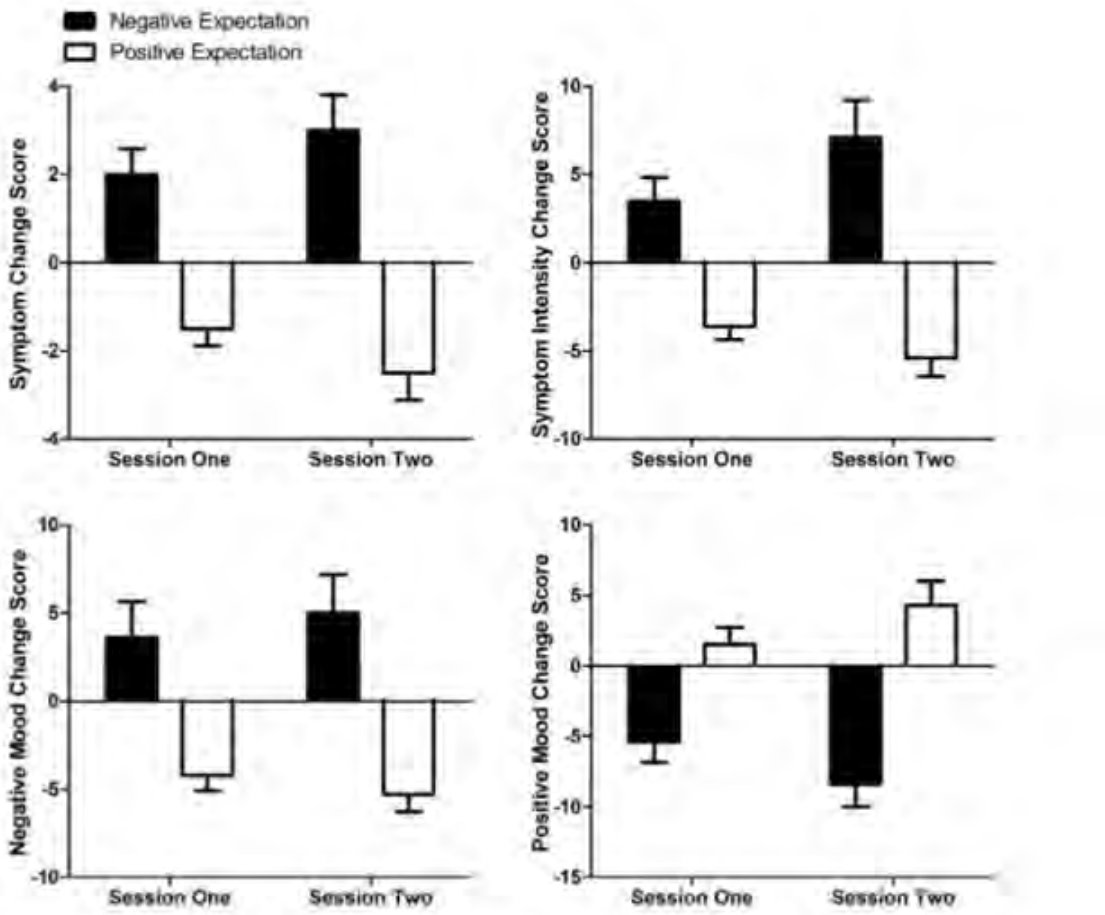


Figure 1. Changes in symptoms, symptom intensity, and mood in negative and positive expectation groups.

Most of the research done by anti-wind campaigners has been conducted outside of the ethical framework to which registered practitioners are expected to submit. Dr. Amanda Harry's surveys of health complaints in the United Kingdom contained leading questions and framing that were likely to increase negative impacts. Dr. Michael Nissenbaum, also of the Society for Wind Vigilance, performed similarly challenged surveys in Maine. He then collected more data from the same people in whom he had likely introduced bias and symptoms, and wrote a report on the results, one of many challenges with his report (see two critical reports in the same journal).

However, these biased researchers have operated without ethical oversight from medical oversight organizations. That is starting to change.

On April 23, 2013, Amber Jamieson at Crikey reported that the National Health and Medical Research Council of Australia was investigating Sarah Laurie for medical ethics violations. If found guilty, Laurie could face a fine of up to $30,000 AUD. Laurie could also be the subject of lawsuits charing that additional harm. Both Sarah Laurie and Carmen Krogh have ignored direct requests to stop spreading unfounded health fears which are likely to be causing health issues.

The Waubra Foundation responded with a media release on May 9, 2013. The organization states that there is a effort to denigrate and distract from the Waubra Foundation's campaign against wind energy and declares that an Independent Commission Against Corruption or Royal Commission should be struck to determine who is commencing the attack. They do not provide any explanation as to why Laurie's public record statements regarding research she is undertaking without oversight and people she is providing health guidance to while unregistered were misinterpreted, they merely deny the charges and claim they are malicious.

They state that these accusations will damage Ms. Laurie's reputation. However, Laurie is already listed on Australia's Quack Watch site and was a nominee for the Australian Skeptic's association's Bent Spoon Award for 2013, and has been referenced in the same sentences as Australia's dangerously deluded anti-vaccination campaigners.

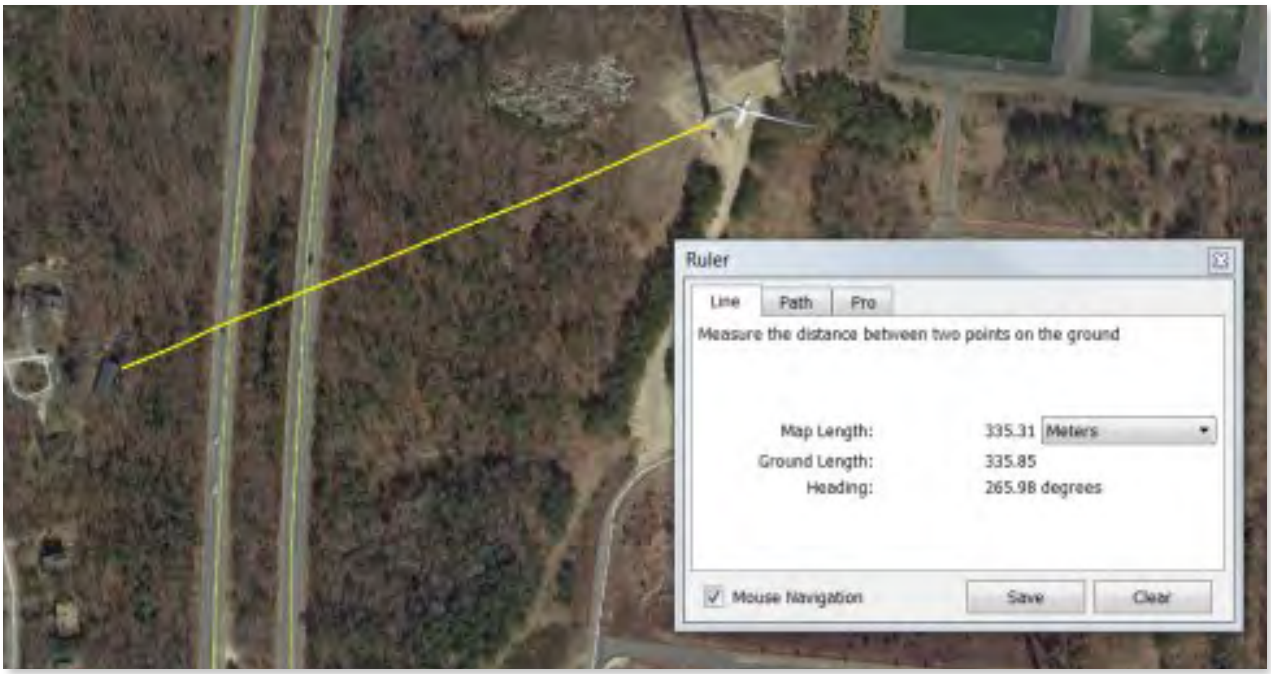
The outcome to date of the ethics complaint is that Ms. Laurie must stop referring to herself as doctor based on an agreement with the Australian Health Practitioner Regulation Agency (AHPRA). Despite this, she continues to refer to herself as Dr. Sarah Laurie in court proceedings she engages in. And a key director of the Waubra Foundation, Michael Wooldridge, is facing an Australian ban of up to ten years on being a Director of a company based on his part in the collapse of Prime Trust and an illegal $33 million AUD offer to a businessman.

Another ethics-challenged anti-wind medical professional is Dr. Bill Studzienny, a rural dentist in the Manitoulin Island region of Ontario. Studzienny is actively refusing to serve long-time patients who support a local wind farm. Because the local First Nations tribe is building the wind farm on their land, Studzienny is almost entirely stopping service to native Canadians. The Human Rights Tribunal and the Royal College of Dental Surgeons have received complaints and are investigating Studzienny's actions. The Royal College of Dental Surgeons recently charged Studzienny with four allegations of disgraceful, dishonourable or unethical conduct.

Falmouth Wind Farm Case: The Outlier

In 2010, the town of Falmouth, Massachusetts constructed a pair of Vestas V82 1.65 MW wind turbines on their waste water treatment plant. After the first wind turbine became operational, nearby residents started complaining about noise. There are a few interesting circumstances related to the wind turbines in Falmouth.

Most of the closest homes are on the other side of a divided highway, Route 28, and when the highway is busy there is considerably more ambient noise in the area.



Falmouth turbine showing the closest home located across a divided highway.

As can be seen from the Google maps image, the closest home is 335 meters or 1099 feet from the wind turbine. Given that there is a divided highway which provides much higher levels of ambient noise much of time, the distance seems potentially reasonable. This isn't a quiet area most of the time and wind energy noise is typically highest when wind noise itself masks it.

The turbines were originally intended for another site. They were purchased by the Massachusetts Technology Collaborative for a site in Orleans, Massachusetts. That project didn't go ahead and the turbines were sold to two different organizations for deployment in Falmouth, which had been considering 1.5 MW wind turbines.

There was a specific noise complaint related to a "bong" sound that was traced to a misaligned inertial damper and corrected by Vestas. There are occasional mechanical

challenges in wind farms as with any large piece of machinery which can lead to it being noisier than expected until corrected. This occurred in Falmouth and was corrected.

Massachusetts and Falmouth combined have three provisions in their noise guidelines and statutes. Falmouth required that wind farms meet the 40 decibels A-weighting (dBA) limit which is in agreement with World Health Organization guidance for environmental noise of an annual average of 40 dBA outside homes (dBA indicates decibels in the A-filtered scale which is what humans hear best and is agreed time-and-again to be the appropriate choice for wind noise assessments). The Massachusetts Department of Environmental Protection (DEP) requires that there be no more than a 10 dBA increase in a specific standard of averaged noise and that there be no 'pure tone' conditions which cause specific spikes in specific frequencies which are disruptive.

Noise modeling projections after the first turbine was constructed, including a ten-day noise testing period by HMMH, found that under certain circumstances the combination of the two turbines might occasionally exceed the 10 dBA increase limit at two homes on the other side of the highway. Noise modeling standards assume that the wind moves directly through each turbine to the receptors.

In May 2012, additional sound testing was performed by the DEP (This was done using non-standard approaches it appears, including a noise averaging approach which is not aligned with acoustic's industry standards and would tend to skew results high, and a peak noise determination approach which is also not aligned to industry standards). The complainants selected the wind conditions under which the greatest noise was experienced, and that became the basis for testing.

It determined that the wind turbines did exceed the 10 dBA threshold at night at just one home. Interestingly, this home is not one of the closest homes across the highway, but a home to the south at 211 Blacksmith Shop Road. Averaged noise calculations using the non-standard approach when turbines were operating were not included in documentation, but ambient noise approached 40 dBA without turbines so it can be assumed that under the worst circumstances noise outside of some homes with turbines exceeded an average of 40 dBA.

The 10 dBA guidelines have a solid rationale, because as the WHO guideline documents, if maximum noise inside a bedroom exceeds 45 dBA maximum more than 10-15 times in a night, sleep can be sufficiently disrupted to cause concern. The WHO guidelines point out that partially closing windows can reduce noise inside bedrooms by 10-15 dBA. So does the empirical evidence show that noise inside bedrooms was outside of WHO standards? No, it doesn't. The worst noise was around 50 dBA outside of homes and with partially closed windows that would likely have been 40 dBA or lower inside bedrooms. And given that the testing was only done under conditions identified as worst by the

complainants, it's unlikely that the World Health Organization guideline of 40 dBA annual average outside of homes was exceeded either.

The final circumstance that is interesting about this case is that Massachusetts (and New England in general) is a locale where anti-wind campaigners have created health scares in residents related to wind energy. Dr. Nina Pierpont, who is at the epicenter of the psychogenic ailments related to wind energy, is a resident in the region, and in fact interviewed Neil Andersen regarding his symptoms in 2011. As has become clear from other court cases, the evidence presented, and further studies in Australia and New Zealand, Dr. Pierpont creates symptoms in those near wind turbines by raising health fears and triggering the nocebo effect in them.

In 2013, the town of Falmouth had reduced the turbine operating hours to 16 hours per day, eliminating noise from the turbines at night. However, Neil and Elizabeth Andersen, who lived at 211 Blacksmith Shop Road, did not consider that adequate and brought a civil action to have the turbines shut off for twelve hours a day instead of eight and they won. Pertinent quotes from the decision include the following:

> *The Andersens have submitted affidavits and medical records supporting their claim that the nuisance produced by the turbines has resulted in substantial and continuous insomnia, headaches, psychological disturbances, dental injuries, and other forms of malaise. The court finds the Andersens' claims that they did not experience such symptoms prior to the construction and operation of the turbines, and that each day of operation produces further injury, to be credible.*
>
> *Thus, a turbine schedule of 7am to 7pm, Monday through Saturday, would provide seventy-two operational hours per week and provide substantial mitigation of the proven (at this point) harm, with no irreparable harm to the Town. While the Town may suffer some financial penalties for reduced REC production and a decrease in expected revenue generation, the risk of major default on various financing agreements or damage to the equipment from prolonged shut down is likely avoided. [the judge adds some holidays later in the decision]*

In this case, according to the data, there was a noise problem with one of the turbines that was fixed. The turbines operated within World Health Organization guidelines for community noise requirements but were perceived to be noisy especially under certain

wind conditions. A single judge out of the 49 cases that considered medical information found the wind health impact claims to be credible, although there is no documentation I was able to find that medical experts were brought in as witnesses in this case.

Of course, anti-wind campaigners such as Sarah Laurie of Australia and Carmen Krogh of Canada now reference this decision in their submissions to wind farm siting bodies around the world as if it is proof, as opposed to an interesting outlier.

Conclusion

Wind energy has been in court for health-related complaints at least 49 times in five English-speaking countries. The courts have dismissed all but one of the cases and that case is clearly an outlier and circumstantial.

Municipalities and other levels of government involved in wind farm siting can rest assured that citizens are not put at risk by wind farms, and further, that vexatious cases brought by those opposed to wind farms will not succeed on health grounds. In civil cases, judges have typically awarded costs to the defending organizations, so while court cases are time consuming, organizations will typically not find them costly otherwise.

Court cases often occur after anti-wind campaigners travel to potential wind farm sites to spread health and other scares. Municipalities, companies, and organizations considering wind farms would benefit by working to establish good consultative relationships early with future wind farm neighbors, providing them with clear and accurate information about impacts and benefits. This will assist in making the citizens relatively immune to the hyperbole of anti-wind groups, and prevent frivolous court cases.

The courts have spoken. Wind farms do not cause health problems.

Addendum: 49 Cases Related to Wind Farms and Health

This addendum contains the full set of 49 cases which were found to have heard evidence pertaining to wind farms and health. To aid in preparation of legal defenses, a link to the decision is provided as well as the indexed name for the case used in the legal system. Almost all referenced links point to decision databases in the jurisdictions, but some point to decision documents maintained on other sites. See the next page for the full list of wind health cases.

Wind Farm Health Decisions from Courts

As of July 2014

Year	Geography	Wind Farm	Type*	Indexed Name	Link	Decision	Key Quote
2014	Ontario, Canada	Bow Lake	Environment	Fata v. Director, Ministry of the Environment	https://www.ert.gov.on.ca/files/201407/00000300-EA23A32ECJO026-EG94263845O026.pdf	In favour of wind farm	*There is one seasonal, unserviced hunting cabin nearly 900 metres away from the nearest Project turbine and seven other seasonal hunting cabins and camps within 1500 metres of the Project turbines. Although these eight locations do not meet all of the characteristics of a noise receptor set out in the Technical Guide for Renewable Energy Approvals published by the Ministry of the Environment ("MOE") given that they are not serviced by any municipal services (sewer or water) or utilities and are seasonal dwellings, they were included as noise receptors in the noise assessment as a conservative measure.* *[93] For the above-noted reasons, the Tribunal finds that the Appellant has not established that the Project, operating in accordance with the REA, will cause serious harm to human health due to emissions of sound or vibrations, visual or social impacts, intereference with access to or enjoyment of property, or fire. The evidence on annoyance caused by visual impacts amounts to an expression of concern, which is insufficient to meet the test in s. 145.2.1 of the EPA. In addition, the Appellant has not established any breach of the Charter. As a result, Mr. Fata's appeal is dismissed.*
2014	Ontario, Canada	Armow	Environment	13-124 KROEPLIN V. MOE	https://www.ert.gov.on.ca/english/decisions/index.htm	In favour of wind farm	*[81] Dr. [Kieran] Moore gave evidence that annoyance is not a medical condition or diagnosis, but is a psychological state that is under the control of an individual, noting that it is up to an individual to have coping mechanisms to deal with annoyance. He stated that many new technologies can cause annoyance or fear, including wi-fi, immunization and fluoridated water, in spite of a lack of scientific documentation of population harm.* *[207] The evidence regarding health effects from other Ontario wind energy projects was provided by the post-turbine witnesses. The Appellants did not call any medical experts to address either the generic case linking wind turbines and harm to health or the specific issue of the cause of the symptoms and conditions experienced by these post-turbine witnesses. The medical records put into evidence from these witnesses in some cases confirmed serious medical conditions, but none of their records included a physicians' note stating an opinion that the cause, or the worsening, of their conditions was due to exposure to wind turbines.* *[209] Therefore, the only evidence before the Tribunal that the post-turbine witnesses suffered harm as a result of exposure to wind turbine emissions was the personal assessment of each of those witnesses.*
2014	Ontario, Canada	South Kent	Environment	8/7/20148/7/2014	http://www.ert.gov.on.ca/files/201401/00000300-DGQ52F50A9O026-EAS449407EO026.pdf	In favour of wind farm	*The Tribunal finds that there was no credible evidence of cumulative or additive effects from the noise of the wind turbines, or that there is a +/- 5 dBA margin for error. [...] the Tribunal accepts the evidence of Dr. McCunney that the predicted sound levels in the bunkhouse and the greenhouses attributable to noise from the wind turbines P038 and P039 will not cause serious harm to the Appellant's employees.*
2014	Ontario, Canada	K2 Wind Huron County	Environment	Drennan v. Director, Ministry of the Environmen	http://www.ert.gov.on.ca/files/201402/00000300-DH74041431O026-EB64ED4669O026.pdf	In favour of wind farm	*the Appellants had not established that the threshold to establish a deprivation or "serious psychological or physical harm" had been met.*
2014	Ontario, Canada	Ostrander Point	Higher	Ostrander Point GP Inc. and another v. Prince Ed	Pending - try here later http://www.ontariocourts.ca/scj/decisions/	For the wind farm	This judgment set aside the ruling of the 2013 Ostrander Point ERT ruling related to harm to the Blanding's Turtle, upheld the rejection of medical harm, upheld the rejection of harm to birds and upheld the rejection of harm to alvar (plant life). Related solely to the health aspect: *[120] APPEC says that the Tribunal erred in this conclusion because it subjected their evidence to a standard of scientific certainty rather than deciding it on balance of probabilities. I do not agree. In my view, the core problem with APPEC's submission is that it confuses the standard for admissible evidence with the standard to be applied in deciding the ultimate issue, that is, whether the test under s. 145.2(2) has been met.* *[121] [...] For a court to conclude that a novel scientific theory is reliable, there must be more than a finding that the theory is more probable or more likely than not. Rather, it requires the fact finder to be satisfied that the theory is, in fact, a reliable one.* *[123] The Supreme Court of Canada has set out four factors to be considered in determining whether threshold reliability is met. In R. v. J.-L.J., [2002] 2 S.C.R. 600, the four factors were identified, at para. 33, as:* *(i) whether the theory or technique has been tested;* *(ii) whether the theory or technique has been subjected to peer review and publication;* *(iii) the known or potential rate of error or the existence of standards; and,* *(iv) whether the theory or technique used has been generally accepted.* *[124] Viewed from the medical perspective, and that is the perspective that is relevant in this case since harm to human health is being asserted, the expert evidence offered by APPEC, through Dr. McMurtry, failed when tested against any of these factors.* *[128] The Tribunal's conclusion on this issue is a reasonable one. Consequently, there is no basis for this court to interfere with that conclusion.*

2014	Alberta, Canada	Bull Creek	Utility	1646658 Alberta Ltd., Bull Creek Wind Project	http://www.auc.ab.ca/applications/decisions/Decisions/2014/2014-040.pdf	For the wind farm	This is the first wind farm approval which saw substantial submissions by an international group of non-expert 'experts' opposed to wind energy. They have previously been active in Australia and Ontario, but never in Alberta. *435. The Commission has carefully reviewed the evidence filed in this proceeding regarding the health effects of wind turbines. In the Commission's view, the evidence filed in the proceeding does not support the proposition that the audible and inaudible (low frequency noise and infrasound) that would be produced by the project would result in health effects for area residents. The Commission recognizes that operation of the project may result in annoyance for some area residents and that the more subjective elements of this annoyance may not be mitigated for all residents. Notwithstanding the potential for annoyance, the Commission is satisfied that adherence to AUC Rule 012, and the project's 40 dBA Leq nighttime PSL will protect nearby residents, including children, the chronically ill and the elderly from sleep disturbance and other health effects related to turbine noise. In making this decision, the Commission specifically had regard to pre-existing medical conditions of J.B., C.H. and H.B. and their confidential medical evidence. To ensure compliance with AUC Rule 012 and the PSL, the Commission would include the conditions described in the previous section for noise monitoring that would include monitoring for low frequency noise at various locations, including the residences of J.B., C.H. and H.B.*
2014	Ontario, Canada	Adelaide	Environment	Wrightman v. Director, Ministry of the Environm	http://www.ert.gov.on.ca/files/201402/000003 00-DHG5AB711HO026-EBK496720WO026.pdf	For the wind farm	*[210] The Tribunal finds that the Appellants have not established that engaging in the Project as approved will cause serious and irreversible harm to plant life, animal life or the natural environment.* *[211] The Tribunal finds that the Appellants have not established that engaging in the Project as approved will cause serious harm to human health.* *[212] The Tribunal dismisses the constitutional challenge to s. 142.1 of the EPA on the basis that the Appellants did not proceed with this issue in their appeal.*
2014	Ontario, Canada	Ernestown Wind Farm	Environment	Bain v. Director, Ministry of the Environment		For the wind farm	*[44] The Tribunal finds that the Appellants and the presenters have not established that engaging in the Project in accordance with the REA will cause serious harm to human health.*
2013	Ontario, Canada	Melancthon Extension	Environment	Bovaird v. Director, Ministry of the Environment	http://www.dufferinwindpower.ca/Portals/23/Downloads/Final/ERT%20decision%20DWPI%20dec%2023-13.pdf	In favour of wind farm	*the evidence in this proceeding does not establish a causal link between wind turbines and either direct or indirect serious harm to human health under the conditions imposed in the REA requiring a setback distance of 550 m, and a maximum noise level of 40 dBA.*
2013	Ontario, Canada	Ostrander Point	Environment	Alliance to Protect Prince Edward County v. Director, Ministry of the Environment	http://www.newswatchcanada.ca/13002d1.pdf	Against wind farm due endangered turtle	*The evidence in this proceeding did not establish a causal link between wind turbines and either direct or indirect serious harm to human health at the 550 m set-back distance required under this REA.*
2013	Victoria, Australia	Cherry Tree	Civil	Cherry Tree Farm Pty Ltd v Mitchell Shire Council	Interim decision: https://www.vcat.vic.gov.au/sites/default/files/cherry_tree_wind_farm_pty_ltd_v_mitchell_shire_council_interim_decision.pdf Final decision: http://www.vcat.vic.gov.au/sites/default/files/cherry_tree_wind_farm_pty_ltd_v_mitchell_shire_council_decision.pdf	In favour of wind farm	*the views of NSW Health as reported in the Bodangora determination and the Victorian Department of Health publication, expressly state that there is no scientific evidence to link wind turbines with adverse health effects. These are the views of State authorities charged by statute with the protection of public health.* - the tribunal wisely defers to public health authorities And interestingly: *The respondents have been unable to refer the Tribunal to any judgment or decision of an environmental court or tribunal which has found that there is a causal link between emissions from a wind farm and adverse health effects on nearby residents.*
2013	Massachusetts, USA	Falmouth	Higher	TOWN OF FALMOUTH vs. TOWN OF FALMOUTH ZONING BOARD OF APPEALS & others	http://waubrafoundation.org.au/wp-content/uploads/2013/11/11-22-13-FalmouthZBApreliminaryinjunctiondecisionandorder.pdf	Against wind farm	*The Andersens have submitted affidavits and medical records supporting their claim that the nuisance produced by the turbines has resulted in substantial and continuous insomnia, headaches, psychological disturbances, dental injuries, and other forms of malaise. The court finds the Andersens' claims that they did not experience such symptoms prior to the construction and operation of the turbines, and that each day of operation produces further injury, to be credible. Taking this evidence of irreparable harm in conjunction with the moving parties' substantial likelihood on the merits of their claim to uphold the ZBA's finding of an ongoing nuisance created by daily 7am to 7pm turbine operation, the court finds there is a substantial risk that the Andersens will suffer irreparable physical and psychological harm if the injunction is not granted. See Packaging Indus. Group, 380 Mass. at 617.3* *As previously articulated in this court's Interim Order of Decision, the Andersens have a substantial likelihood of success on the merits of their position that the ZBA's decision that both turbines created a nuisance prohibited by Code of Falmouth §240-110 at the property in question, and its direction that the "Building Commissioner take all necessary steps to eliminate the nuisance caused by the operation of the wind turbines", was based on a legally reasonable ground that was sufficiently supported by facts contained within the record.* *240-110 - No use shall be permitted which would be offensive because of injurious or obnoxious noise, vibration, smoke, gas, fumes, odors, dust or other objectionable features, or be hazardous to the community on account of fire or explosion or any other cause. No permit shall be granted for any use which would prove injurious to the safety or welfare of the neighborhood into which it proposes to go, and destructive of property values, because of any excessive nuisance qualities.*
2013	New Zealand	Te Rere Hau	Higher	New Zealand Wind Farms Limited vs Palmerston North City Council		For the wind farm	*[3] There is no proof that specific noise levels in the consent conditions were, or are being breached. Monitoring is ongoing to determine that question. The appellant accepts however, that noise generated by the wind farm is greater than was predicted in the application and that residents are also affected to a greater degree than predicted.* *[30] It is not yet known if the condition 4 upper limit of 40dBA or background and 5dBA is being breached. Initial calculations by Mr. Halstead, the current acoustic engineer for NZWL, suggested that some downwind conditions (i.e. wind blowing from an SSE direction) did produce breaches of that standard at one property, but subsequent corrections by NZWL suggested that may have been wrong. Monitoring continues.* *[73] The appellant's appeal is allowed. Declaration 1.9 is set aside. The respondent's cross-appeal is overtaken by the result.*

2013	New Zealand	Hurunui	Environment	Meridan Energy Limited vs Hurunui District and Canterbury Regional Councils	http://www.nzlii.org/cgi-bin/download.cgi/nz/cases/NZEnvC/2013/59	For the wind farm	*[189] [...] rural environments are far from quiet in the sense of there being no sound. The sounds in a rural environment can be 'natural' in the sense of 'arising from nature'(e.g. birdsong, the sound of animals), but they can also be 'unnatural' in the sense of 'being manmade' (e.g. the sound of tractors and farm machinery). Whilst Mr. Carr talked about 'hearing the silence' at his property, there are times when the functions at his property, even if they are within his resource consent provisions, may produce sound which could be viewed by some as unwanted and unnatural in this environment.* *[190] [...] there is no legal right for an existing and tranquil environment to remain so.* *[248] With the amendments we have suggested, we are satisfied that these conditions will adequately mitigate any potentially adverse noise effects and will ensure that amenity values as they relate to noise, are maintained.* *[269] [...] We have concluded that, of the reviews done, the current weight of scientific opinion indicates that there is no link between wind turbine noise and adverse health effects. Dr. Shepherd challenges this but we are not satisfied that Dr. Shepherd's critique of the reviews (as presented to us) is sufficiently robust to outweight their conclusions. Neither are we satisfied that the Makara study is sufficiently robust in its methodology for us to give it the kind of weight that would be required to counterbalance the weight of the other scientific opinion expressed in the reviews.* *[270] Overall we are satisfied that the research establishes that adverse health effects are not likely to arise from the operation of the wind farm.*
2013	New York, USA	Monticello Winds	Higher	Lawrence J. FRIGAULT et al., Respondents–Appellants, v. TOWN OF RICHFIELD PLANNING BOARD et al., Appellants–Respondents, et al., Respondent.	http://caselaw.findlaw.com/ny-supreme-court/1636558.html	For the wind farm	*The Board engaged in a lengthy SEQRA review process, which included hiring an outside consulting firm and conducting no less than 11 Board meetings between the time the permit application was filed in March 2011 and the issuance of the negative declaration in November 2011. The full EAF was replete with studies on environmental issues, including the project's impact on bats and birds, "shadow flicker,"3 noise, cultural resources and visual effect, and the Board afforded members of the public an opportunity to voice their concerns with respect to the project. In addition, the Board received input as to the project's environmental impacts from various state agencies, including the Office of Parks, Recreation and Historic Preservation, the Department of Environmental Conservation, the Department of Transportation, and the Department of Agriculture and Markets.* *At the conclusion of the environmental review process, the Board issued a thorough and reasoned analysis addressing the areas of relevant environmental concern—land, water, air, plants and animals, agricultural land resources, aesthetic resources, historic and archeological resources, open space and recreation, noise and odor, among others—which, in our view, demonstrates that the Board took the requisite hard look at those concerns*
2013	Oregon, USA	Helix Wind Power Facility	Higher	IN RE: the Request for Amendment # 2 of the Site Certificate for the Helix Wind Power Facility. The BLUE MOUNTAIN ALLIANCE; Norm Kralman; Richard Jolly; Dave Price; Robin Severe; and Cindy Severe, Petitioners, v. ENERGY FACILITY SITING COUNCIL; and Site Certificate Holder Helix Windpower Facility, LLC, Respondents.	http://caselaw.findlaw.com/or-supreme-court/1628675.html	For the wind farm	*The ODOE staff report recommended that the council decline to find that a setback of less than two miles posed a significant threat to public health and safety. First, the report explained that the council previously had determined—in an unrelated proceeding—that a 1/4 mile setback was sufficient and that the council since had applied that smaller setback to other wind energy facilities. Second, the report explained that ODEQ noise regulations established a "public health setback" that may exceed 1/4 mile depending on certain circumstances and that the council applied those regulations to all energy facilities. The report therefore recommended that the council follow its own previously established 1/4–mile setback or a setback that otherwise complied with ODEQ regulations, whichever was greater.*
2013	Northamptonshire, United Kingdom	Spring Farm Ridge	Higher	South Northamptonshire Council & Anor v Secretary of State for Communities and Local Government & Anor [2013]	http://www.bailii.org/ew/cases/EWHC/Admin/2013/11.html	Against the wind farm	One of five claims was accepted, that the Inspector needed to assert priority of the Local Plan and didn't. On the subject of noise: *As I see it this Ground was raised and decided at the Inquiry and is not for this Court. The fact that the law recognises that in some cases an Inspector can validly decide to take factors other than ETSU into account does not mean that in other situations an Inspector may not lawfully conclude that ETSU compliance is the right measure. In this case the Inspector considered the matter with care and then decided, unsurprisingly perhaps given the national guidance, to apply ETSU and attach a condition. This was a matter for her to decide and she did so lawfully.*
2012	Ontario, Canada	Haldimand Summerhaven project	Environment	Monture v. Director, Ministry of the Environment	http://www.ert.gov.on.ca/files/201210/00000300-CCT354134JO026-CJ1379458RO026.pdf	In favour of wind farm	*the Tribunal finds that the Appellant has not established that the Project as approved will cause serious harm to human health, or serious and irreversible harm to plant life, animal life or the natural environment, and therefore dismisses the appeal.*
2012	Ontario, Canada	Haldimand Grand Renewable Wind	Environment	Monture v. Director, Ministry of the Environment (Monture 2)	http://www.ert.gov.on.ca/files/201212/00000300-CG34421F05O026-CLV325E3ELO026.pdf	In favour of wind farm	*most of the documentary evidence was obtained from internet sources, prepared by authors not available for cross-examination and not peer-reviewed. As a result, the Tribunal finds that much of this evidence is of limited weight.*
2012	Ontario, Canada	South Kent	Environment	Chatham-Kent Wind Action Inc. v. Director, Ministry of the Environment	http://www.ert.gov.on.ca/files/201212/00000300-CG34FECC5JO026-CL540EA733O026.pdf	In favour of wind farm	*"the belief and truths of the person with respect to their mental or physical health is again acquired through response to the object, not caused by the object."* - participant's attempt to say that the nocebo effect is true and a reason to forbid wind farms, rejected by the Tribunal

2012	New Zealand	Te Rere Hau	Environment	Palmerston North City Council vs. New Zealand Windfarms Limited	http://www.nzlii.org/nz/cases/NZEnvC/2012/133.pdf Search: http://www.justice.govt.nz/courts/environment-court/search-environment-court-decisions-from-2006	Against wind farm	Net: no health impacts or health evidence. Context: the Te Rere Hau wind farm used the Windflow 500 turbine, a unique two-blade wind turbine manufactured in New Zealand. Noise modeling was based on a prototype and was found to be inaccurate in production models, as noisy as wind turbines with six times the capacity and with some special tonal characteristics of concern only at 50 meters from the turbines. This is an isolated incident involving an unproven wind turbine which is not used elsewhere. In the initial approval per NZ standards: *WTG sound levels shall not exceed:* *- the best fit regression curve of the A-weighted background sound level (L95) plus 5 dB; and* *- 40dBA* *Whichever is higher.* [outside the residence] In the judgment: *Noise levels measured at the residences for the SSE winds are in the range of 33 - 41 dBA compared to the AEE predictions of 23-26 dBA.* Conclusion: *That the acoustic information supplied in the AEE by the Respondent and the evidence of the Respondent was inaccurate to such an extent that Palmerston North City Council may rely on s128(1)(c) RMA to conduct a review of the noise consent conditions applicable to the Te Rere Hau wind farm.*
2012	Maine, USA	Saddleback Ridge	Higher	FRIENDS OF MAINE MOUNTAINS v. BOARD OF ENVIRONMENTAL PROTECTION	http://caselaw.findlaw.com/me-supreme-judicial-court/1624887.html	Against the wind farm	The wind farm was approved under previously existing 45 dB night time noise limit, but during the ongoing process the night time noise limit was decided to more appropriately be 42 dB, and while the wind farm noise modeling was conservative and under 45 dB, it was not shown to meet the 42 dB limit, so the approval was sent back. *[¶ 17] Because the Board is responsible for regulating sound levels in order to minimize health impacts—and because when doing so it determined that the appropriate nighttime sound level limit to minimize health impacts is 42 dBA—the Board abused its discretion by approving Saddleback's permit applications.9 Although the project's models predict nighttime sound levels slightly below 45 dBA, the Board failed to give the nearby residents the acknowledged protection of the amended rules. We vacate the Board's order and remand for further review using the 42 dBA nighttime sound level limit as introduced in 2 C.M.R. 06 096 375–15 § 10(I)(2)(b)(2012).*
2012	Alberta, Canada	Heritage Wind Farm	Utility	Heritage Wind Farm Development Inc., Decision on Preliminary Question, Decision 2011-239,	http://www.auc.ab.ca/applications/decisions/Decisions/2012/2012-029.pdf	Against the wind farm	Heritage requested revision of wording of an approval paragraph to indicate higher cut in to allow for wind masking and removal of potential night time shut down of wind turbines to achieve noise plan. This was refused, as shut down of wind turibnes may be required to achieve noise limits.
2011	South Australia, Australia	Allendale East	Environment	Paltridge and Ors v District Council of Grant and Anor	http://www.planning.nsw.gov.au/LinkClick.aspx?fileticket=5dDcyuDuGuU%3D&tabid=205&mid=1081&language=en-US	Against wind farm (visual amenity)	*Most of this work, as far as we can discern, has not been the subject of any peer review and none of the witnesses were called to give evidence.* - regarding Sarah Laurie's submission *[142] On the issues of noise and health, we accept the evidence and assessments of Acciona's expert witnesses and where there is any conflict between them and the appellant's expert witnesses we prefer the evidence given by Acciona's experts.*
2011	Ontario, Canada	Chatham Kent Suncor	Environment	Erickson v. Director, Ministry of the Environment	http://www.nrwc.ca/wp-content/uploads/2012/05/00000300-AKT5757C7CO026-BGI54ED19RO026.pdf	In favour of wind farm	*the Tribunal finds decades-old attitudes to cigarettes to be a poor analogy to wind turbines. This is because Ontario already recognizes that there are some risks with respect to wind turbines. That is why there are setbacks.*
2011	Ontario, Canada	Wind farm enabling legislation	Higher	Hanna v. Ontario (Attorney General)	http://canlii.ca/en/on/onscdc/doc/2011/2011onsc609/2011onsc609.html	In favour of wind farm	*Cognizant of the possible health concerns, the minister decided the minimum 550-metre setback was adequate.*
2011	New Zealand	Mt Cass	Environment	Mainpower NZ Limited v Hurunui District Council	http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2011/384.html?query=wind%20farm	For the wind farm	*[430] In response to a question from Mrs McLachlan as to how her [autistic] child might be affected by the predicted maximum 42 dB noise level at the boundary of the McLachlan's farm, Dr Black responded that he would be very surprised if the child was adversely affected through exposure to what he described as 42 dB of broad spectrum noise.314 He amplified this further when he said:315* *It's not a matter of level of noise and it's far from certain that the nature of the noise would be of a type that would upset [the child]. In fact with modern wind turbines, the tonal component to the noise is largely eliminated. In some earlier turbines there could, at times, be quite a tonal component. The broad spectrum white noise which is typical of turbines once you get more than a few hundred metres away from them, is a noise of natural character and one which is generally readily accommodated by people because it becomes undistinguishable from natural noises which people are accustomed. I've had quite a lot of people in communities who were concerned about turbines say to me that after a while they really can't discriminate between the sound to the extent that they do hear it and the wind and if they want to really establish whether it is the wind or the turbine, they really have to face it with both ears facing it and really listen and think about it. (our emphasis)* *[450] The proposal will practically comply with the noise standards in the District Plan. Secondly, as a minimum, noise levels at all rural residential sites are to comply with the guideline limits set out in NZS6808:2010 Acoustics – Assessment & Measurement of Sound from Wind Turbine Generators. The construction of the proposal is to comply with the noise limits set out in NZS6808:1999 Acoustics – Construction Noise.* *[446] A number of submitters expressed concern that the noise from the wind farm could adversely affect children at the Omihi School. The predicted noise level at the McLachlan's dwelling which is 2.3 km from the wind farm is only 25 dBA. As the school is around 4 km from the wind farm , it is Dr Black's opinion that wind farm noise there will be barely audible and that it will have no effect on the pupils.323 Dr Black's opinion was not disputed.*

2011	Maine, USA	Record Hill	Higher	CONCERNED CITIZENS TO SAVE ROXBURY et al. v. BOARD OF ENVIRONMENTAL PROTECTION et al.	http://caselaw.findlaw.com/me-supreme-judicial-court/1560730.html	For the wind farm	*[¶ 7] As part of its review of Record Hill's application, the Department consulted with the Maine Center for Disease Control (MCDC), which issued a report in June of 2009 on the potential health effects from noise produced by wind turbines. The MCDC "found no evidence in peer-reviewed medical and public health literature of adverse health effects from the kinds of noise and vibrations [emitted] by wind turbines other than occasional reports of annoyances, and these are mitigated or disappear with proper placement of the turbines from nearby residences." Although the MCDC's report stated that exposure to high levels of low frequency noise could "be annoying and may adversely affect overall health," the MCDC determined that "these levels appear to be more intense than what is measured from modern wind turbines." The MCDC concluded that there was no reliable evidence that low frequency noise produced by wind turbines would cause significant adverse health effects, and that "[t]here are tremendous potential health benefits to wind turbines, including reductions in deaths, disability, and disease due to asthma, other lung diseases, heart disease, and cancer."* *[¶ 27] We conclude that the Board's findings concerning the health effects of wind turbine noise are supported by substantial evidence in the record. The report of the MCDC and the noise control consultant's opinion both support the finding that the Record Hill Wind Project will not generate unreasonable adverse health effects. Although CCSR submitted contrary evidence, "[w]e cannot reject the Board's finding on the grounds that other evidence in the record supports a different factual finding." See Friends of Lincoln Lakes, 2010 ME 18, ¶ 20, 989 A.2d at 1135. In addition, although CCSR contends that the Board failed to impose further conditions on Record Hill, the Board was not required to do so given its finding relating to the health effects associated with the project.*
2011	Devon, United Kingdom	Den Brook	Higher	Hulme v Secretary of State for Communities and Local Government & Anor [2011]	http://www.bailii.org/ew/cases/EWCA/Civ/2011/638.html	For the wind farm	Provisions for testing for and complying with amplitude modulation stood.
2010	Saskatchewan, Canada	Red Lily	Civil	McKinnon vs RMs Martin and Moosomin, Red Lily Wind	http://www.canlii.org/en/sk/skqb/doc/2010/2010skqb374/2010skqb374.html	In favour of wind farm	*The plaintiff has not shown that irreparable harm will occur in my opinion [Judge J. Mills], and clearly has not shown that there is a high degree of probability that injury will in fact occur.*
2010	New Zealand	Project Central Wind	Environment	Rangitikei Guardians Society Inc v Manawatu-Wanganui Regional Council	http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2010/14.html?query=wind%20farm	For the wind farm	*[207] The wind farm operational noise levels are to comply with the limits set out in NZS6808:1998 Acoustics — The Assessment and Measurement of Sound from Wind Turbine Generators and an updated Standard (which is in the course of review) once it is published. Further, the Rangitikei District Plan noise rules specifically reference this as the standard to be used for the assessment of noise from wind turbines, although the Ruapehu District Plan predates both this standard and the current version of NZS6803.* *[208] NZS6808:1998 sets the limit for a wind farm noise at a level of 40 dBA L95 or 5 dBA above the background, whichever is the greater. The updated Standard would not be adopted if its criteria are less stringent than the 1998 version of NZS6808 (an Augier condition on the consent).* *[209] Mr Botha observed that the maximum predicted noise levels would be well below the limits set out in NZS6808:1998. He said that noise would not be an issue for the Moawhango School, located 3.3km away from the closest turbine, with day time noise levels below those permitted by the Rangitikei District Plan.* *[216] We conclude from the evidence of Dr Black that there would be no health effects of concern arising from the establishment of Project Central Wind.* *[265] The Council's decision in respect of the Meridian wind farm application is confirmed and consent is granted for the proposal as presented to us.*
2010	South Australia, Australia	Hallett	Environment	QUINN & ORS v REGIONAL COUNCIL OF GOYDER & ANOR	http://www.austlii.edu.au/cgi-bin/sinodisp/au/cases/sa/SAERDC/2010/63.html?stem=0&synonyms=0&query=wind%20or%20turbine	In favour of wind farm	*[106] In relation to noise, we accept the evidence of Mr Turnbull that the proposed wind farm will comply sufficiently with the relevant standards. Professor Hansen criticised those standards. He wished for more rigorous methods for noise prediction and compliance testing. Those are largely matters for those bodies which generate the policies and standards, and for the framers of the policy documents which adopt them. Generally, it is our task to apply the policies and standards as they exist.* *[107] It is implicit in the Development Plan that the establishment of a wind farm will result in the introduction of a new noise source in the locality of that wind farm. That is unavoidable with the present state of the technology. The establishment of wind farms is, nevertheless, sought. The Development Plan seeks the avoidance or minimisation of nuisance from excessive noise. The levels ascertained by Mr Turnbull are not excessive in terms of volume. There was no evidence to suggest that a different siting layout, or any other measures, would reduce the noise from the proposed wind farm.*
2010	New South Wales, Australia	Gullen Range	Environment	King & Anor v Minister for Planning; Parkesbourne-Mummel Landscape Guardians Inc v Minister for Planning; Gullen Range Wind Farm Pty Limited v Minister for Planning	http://www.austlii.edu.au/cgi-bin/sinodisp/au/cases/nsw/NSWLEC/2010/1102.html?stem=0&synonyms=0&query=wind%20farm	In favour of wind farm	*154 Inserting subjectivity consent requirements based on an individual's or a group of individuals' reaction to the noise from the wind farm , based on their opposition to the development, is entirely alien to the planning system. Whilst, in some areas such as streetscape impact, individual aesthetic considerations may arise and judgements made upon them, we are unaware of any authority to support the proposition that, where there is a rationally scientifically measurable empirical standard against which any impact can be measured and determined to be acceptable at a particular empirically determined level, that there should be some allowance made for a subjective response to the particular impact. Mr Griffiths was unable to cite any authority in support of such a proposition.*

2010	Victoria, Australia	Sisters Wind Farm	Civil	The Sisters Wind Farm Pty Ltd v Moyne SC	http://www.austlii.edu.au/cgi-bin/sinodisp/au/cases/vic/VCAT/2010/719.html?stem=0&synonyms=0&query=wind%20farm	Against wind farm (exceeds updated noise standards)	Standard changed after initial approval, VCAT ruled that new standard should be applied, wind farm did not meet new standard, but this was overturned on appeal to the Supreme Court. New formal standards were adopted for wind farms, and the Tribunal and the Supreme Court agreed in the end that the new standards should be applied. *[16] The New Zealand standard referenced in the Victorian Planning Guidelines for Wind Energy Facilities 2009 and in Clause 52.32-2 of the Planning Scheme was superseded on 1 March with standard 6808:2010. The new standard retains the limits contained in the 1998 Standard with the substitution of L90 percentile for the L95 in that standard as being more robust. The standard however does allow for, in quiet locations, 'the provision of a lower more stringent limit where a local authority has identified in its district plan the need to provide a higher degree of acoustic amenity'. The standard recommends that the sound from a wind farm in such locations during the evening and night-time not exceed the background sound level by more than 5dB(A) or 35dB(A) L90 (10min) whichever is the greater. The question then arises as to whether we should have regard to this standard and if so whether the subject site warrants special consideration as a quiet location. With respect to the appropriate standard to apply we accept Ms Marshall's submission that under the Interpretation of [17] Legislation Act 1984 the reference to the 1998 New Zealand Standard in the Policy Guideline and the Planning Scheme should be read as a reference to the 2010 New Zealand Standard. The New Zealand Standard is the one referred to in the 2009 Guidelines. It is the adopted standard for the State of Victoria and we find the fact that it is adopted from New Zealand of no particular relevance. We further find that the area impacted by The Sisters proposal is a quiet location as evidenced by the background noise level measurements made by the applicant which were below 35dB(A) at wind speeds up to 6 m/sec.* *[27] A number of issues arise with respect to the cumulative impacts of the two wind farms including the failure of the applicant to identify two of the affected dwellings and the different predicted level of the impact. We find in this regard that the two dwellings failed to be identified by Ms Crawford will be impacted to an identical extent as the dwellings most proximate to them and that the difference in the extent of impact predicted in the two reports is a function of the different degree of conservatism in the model inputs. Overall we conclude that the 2010 New Zealand Standard should have been applied in assessing the cumulative impact and that if this had been done the five houses identified by Mr Delaire would fail to meet the Standard and the most easterly of the dwellings assessed by Ms Crawford would be below the limit.*
2010	Ohio, USA	Champaign County	Higher	IN RE: Application of BUCKEYE WIND, L.L.C., for a Certificate to Construct Wind–Powered Electric Generation Facilities in Champaign County, Ohio; Union Neighbors United et al., Appellants; Power Siting Board et al., Appellees.	http://caselaw.findlaw.com/oh-supreme-court/1609087.html	For the wind farm	*{¶ 33} The neighbors' first three propositions of law assert that the operational noise limits set by the board are either vague or unreasonable. To the contrary, the order sets discernible noise limits. That the standard is flexible poses no legal problem—an agency, particularly when facing new issues, may proceed on an incremental, case-by-case basis. See Securities & Exchange Comm. v. Chenery Corp., 332 U.S. 194, 202–203, 67 S.Ct. 1575, 91 L.Ed. 1995 (1947) (an "agency may not have had sufficient experience with a particular problem to warrant rigidifying its tentative judgment into a hard and fast rule," and thus "the agency must retain power to deal with the problems on a case-to-case basis if the administrative process is to be effective"). As for the neighbors' proposed standards, the testimony of Buckeye's acoustic consultant showed that they were unrealistic and would effectively prohibit the development of wind energy in Ohio. Thus, the board properly rejected appellants' proposals.*
2010	Cumbria, United Kingdom	Crosslands Farm	Higher	Barnes & Anor v Secretary of State for Communities and Local Government [2010]	http://www.bailii.org/ew/cases/EWHC/Admin/2010/1742.html	For the wind farm	The judge rejected all of the noise-related claims for appeal, as well as all of the other claims as well.
2010	Denbighshire, United Kingdom	Gorsedd Bran	Higher	Tegni Cymru Cyf v The Welsh Ministers & Anor [2010]	http://www.bailii.org/ew/cases/EWHC/Admin/2010/1106.html	For the wind farm	*As I pointed out in paragraph 17 of this judgment the First Defendants accept that if the Claimant establishes any of its main grounds of challenge the Inspector's decision should be quashed with the consequence that the Claimant's planning appeal should be reconsidered. I have reached the conclusion that the Inspector erred in law in at least one important respect. In my judgment, he failed to provide adequate reasons for his conclusion that the noise impact of the proposed development was unacceptable; his reasoning gives rise to a substantial doubt, at the very least, as to whether he erred in law when reaching his conclusion upon the issue of noise impact.*
2010	Devon, United Kingdom	Den Brook	Higher	Hulme, R (on the application of) v Secretary of State for Communities & Local Government [2010]	http://www.bailii.org/ew/cases/EWHC/Admin/2010/2386.html	For the wind farm	The judge rejected all of the noise-related claims for appeal, as well as all of the other claims as well.
2010	Denbighshire, United Kingdom	Gorsedd Bran	Higher	Tegni Cymru Cyf v The Welsh Ministers & Anor [2010]	http://www.bailii.org/ew/cases/EWCA/Civ/2010/1635.html	Against the wind farm	There was no indication of health concerns, just nuisance due to more evenings when wind turbines would be audible. *Mr Norris QC submits that this involved an error of law. The volume of noise did not increase, merely the frequency. He contended, as I think he had to do, that the increase in the frequency of noise was not a material factor for the Inspector to consider. Furthermore, he said it would undermine the consistency which the guideline is intended to provide, if in effect an Inspector could depart from it in this way. The guidelines were grounded in an objective analysis of noise levels, and it was not appropriate to depart from a guideline merely as a consequence of his consideration of the subjective perceptions of the residents.* *I disagree. As my Lord, Lord Justice Pitchford, has indicated, it seems to me that the duration of an interference is plainly a material consideration when determining whether the level of noise is acceptable. I see the force of Mr Norris QC's submission that there is a degree of uncertainty and inconsistency if guidelines such as those enunciated in ETSU 97, based on objective evidence, are departed from too readily; but as Carnwath J, as he then was, pointed out in the Filton case to which Pitchford LJ has referred, ultimately the legal position is that it is for the planning inspector to exercise his judgment. Provided he has had regard to material considerations and has not reached perverse conclusions, then it is not for the court to interfere.*
2009	Pennsylvania, USA	Laurel Ridge	Higher	Arthur and Elke PLAXTON, Appellants v. LYCOMING COUNTY ZONING HEARING BOARD and Laurel Hill Wind Energy, LLC.	http://caselaw.findlaw.com/pa-commonwealth-court/1499562.html	For the wind farm	*In light of the foregoing, we believe the ordinance amendments are valid because they promote public health, safety or welfare and the provisions are substantially related to the purpose the amendments seek to serve. More specifically, the goal of the ordinance amendments, to harvest wind as a natural resource and to convert it to energy as a source of power to provide electricity to the public, promotes public health, safety or welfare, and the provisions of the amendments are substantially related to this purpose. Objectors did not meet their heavy burden of proving a lack of any rational relationship to a legitimate governmental purpose.*

2009	Norfolk, United Kingdom	Lotus Cars	Higher	The Friends of Hethel Ltd, R (on the application of) v Ecotricity [2009]	http://www.bailii.org/ew/cases/EWHC/Admin/2009/2856.html	For the wind farm	*Notwithstanding PPS 22, and these important decisions by inspectors, in my view the challenge in this case on noise gets nowhere. The choice of locations for measuring noise was agreed between the council's environmental services department and Ecotricity's noise consultants. Officers from that department considered Chapter 11 of the Environmental Statement and concluded that the noise measurements were in compliance with ETSU-R-97. (The environmental expert, Dr Towner, employed by Mr and Mrs Watson, of East Carleton, reached a similar conclusion). The commitee report provided sufficient information and guidance to enable the committee's members to reach a decision on noise impact, applying the relevant considerations. It summarised the noise measurements, the expert opinion and the objections of residents. It noted that full copies of all comments could be viewed on the council's website. The non-technical summary of the Environmental Assessment, which was with the report, provided more detail. At the committee meeting residents raised concerns directly with members before the decision was taken.*
2008	Victoria, Australia	Newfield	Civil	Acciona Energy Oceania Pty Ltd v Corangamite SC	http://www.austlii.edu.au/cgi-bin/sinodisp/au/cases/vic/VCAT/2008/1617.html?stem=0&synonyms=0&query=wind%20farm	For the wind farm	*[73] Having carefully reviewed the material, we are satisfied that the outcome of Mr Delaire's analysis shows the noise impacts upon dwellings within range of the proposed wind farm would or could comply with NZS6808. Compliance testing can ensure that outcome. We are not persuaded that some of the uncertainties referred to by Dr Broner are valid given Mr Delaire's responses nor do we find it appropriate to require a 5dbA allowance to be required "up-front" when the standard we are obliged to apply operates differently. Micro-siting could alter the results but assessment in considering any shift of the turbines and then compliance testing can ensure the required standards are met.* *[103] There is no evidence of health impacts that persuades us that rejection of the permit application is warranted given the proposal's compliance with the applicable standards. If there are significant issues arising then there needs to be some independent assessment and documentation leading, if required, to variations in the standards applied in Victoria.*
2008	Devon, United Kingdom	Fullabrook Down	Higher	North Devon District Council, R (on the application of) v Secretary of State for Business, Enterprise & Regulatory Reform & Anor [2008]	http://www.bailii.org/ew/cases/EWHC/Admin/2008/1700.html	For the wind farm	*Thus, there was no change in policy which might have made it only fair to invite further representations. The department did not, as the claimant submits, rely on the Salford report as a justification for the use of the ETSU methodology. The department's position was consistently that noise assessments of wind farms should be carried out in accordance with the ETSU report, and the Salford report did not cause the department to alter that position. In any event, the department's approach to this issue in paragraph 4.12 of the decision letter merely echoed the statement that had been issued on 1st August 2007. It had been open to the claimant to make further submissions, or to ask for an opportunity to make further submissions, to the defendant after the announcement on 1st August 2007. But for whatever reason it did not do so, perhaps because it recognised that the position as it had existed at the inquiry had not been altered in any way. For these reasons, I reject the claimant's noise challenge.*
2007	Victoria, Australia	Hepburn Wind	Civil	Perry v Hepburn SC	http://www.austlii.edu.au/cgi-bin/sinodisp/au/cases/vic/VCAT/2007/1309.html?stem=0&synonyms=0&query=Hepburn%20Shire%20Council	In favour of wind farm	*The noise criteria are not designed to achieve inaudibility. Turbine noise may be audible on adjacent properties even if the proposal complies with the applicable standard.*
2007	Victoria, Australia	Yarram	Civil	Synergy Wind Pty Ltd v Wellington SC	http://www.austlii.edu.au/cgi-bin/sinodisp/au/cases/vic/VCAT/2007/2454.html?stem=0&synonyms=0&query=wind%20farm	For the wind farm	*76 The assessment and impact of noise is perhaps the most contentious matter for WEF's. There appears to be much misconception and misunderstanding of the potential impacts from noise. [39] We do not intend to deal with what can only be described as 'red herrings', unsubstantiated materials and disinformation.* *[39] This included matters relating to wind shear effects, infra-sound (low frequency sound), intermittent effects and sensitivity of residents.* *81 A summary of wind directions monitored for the site[42] indicates that the dominant wind directions (for 60-70% of the period from 1 July 2005 to 1 July 2006) are in an arc of WNW to SSW. Having regard to this fact, we deduce that those dwellings lying in the lee of these wind directions (i.e. to the NNE to ESE) are those that will most often be exposed to wind turbine generated noise. These include the Stoner, Lynch and Danusar/Vyner dwellings, the same dwellings in the Marshall Day assessment selected as being representative for these areas. It is the evidence of Mr Marks that the sound levels at these locations will be within acceptable limits. Despite Mr Hardings' protestations about the inadequacies of the NZ6808:1998 standard, his own calculations also indicate that the noise levels at these locations will also be below the acceptable limits set under the WEF Guidelines.[43]* *82 In the absence of evidence to the contrary, we find that the assessment of noise impacts has been undertaken in an appropriate manner and that there is no basis for refusal in relation to acoustic/ noise impacts.*
2006	Wisconsin, USA	Twin Creeks Wind Park	Higher	ROBERTS v. MANITOWOC COUNTY BOARD OF ADJUSTMENT	http://caselaw.findlaw.com/wi-court-of-appeals/1303962.html	For the wind farm	*¶ 28 Roberts also contends that evidence presented in opposition to the wind energy park was disregarded by the board. Roberts laments, "Had the Board been willing to show even the least bit of open-mindedness or curiosity, they would have discovered substantial concerns, supported by evidence in the Record which clouded the purported virtues of wind power[.]" However, it is not "substantial concerns" that will overcome the Board's decision, but rather the absence of substantial supporting evidence. The Board must make its decision based on substantial evidence, which is defined as "such relevant evidence as a reasonable mind might accept as adequate to support a conclusion." Stacy v. Ashland County Dep't. of Public Welfare, 39 Wis.2d 595, 603, 159 N.W.2d 630 (1968) (citations omitted).* *¶ 29 Roberts specifically contends that the Board did not consider the hazards of ice fling, the impact of ambient noise and shadow flicker, or the dangers to wildlife. Our review of the record indicates otherwise.*
2006	Scotland, United Kingdom	Borrowston Mains	Higher	CRE Energy Ltd Re: A Decision Of The Scottish Ministers [2006] ScotCS CSOH_131 (29 August 2006)	http://www.bailii.org/scot/cases/ScotCS/2006/CSOH_131.html	Against the wind farm	The judge upheld the refusal of granting an application for the wind farm based on visual impact, but agreed with the appellant and others that the previous decision had been error-riddled regarding wind farm noise.

2001	Victoria, Australia	Toora	Civil	Thackeray v Shire of South Gippsland	http://www.austlii.edu.au/cgi-bin/sinodisp/au/cases/vic/VCAT/2001/739.html?stem=0&synonyms=0&query=wind%20farm	For the wind farm	*7.11 Further, the Tribunal gains confidence that the modelling results are more likely to be an overprediction rather than an underestimate as all experts agree the model is conservative. When predicting the noise level at a point away from the wind turbine, the model assumes the wind is blowing from the turbine to the point of interest, this is because noise transmits better downwind than upwind. When the model is calculating the total noise at a site due to all of the turbines, it is consequently assuming that the wind is blowing towards the point of interest from every turbine. This obviously is incorrect and as the wind can come from one direction only the actual noise due to the wind turbines must be less than the model predicts. Mr Goddard in cross examination considered that if an allowance was made for the wind blowing away from the measured site, there would be an up to 3dBA drop in the noise levels from those predicted by the model.* *7.18 The Tribunal considers it more appropriate to use a standard specific to a use, as opposed to a general standard which is a guideline under review at this time. Further the New Zealand standard is designed to cater for the control of a dynamic system taking account of the varying wind speeds. It has a well thought out and clearly set down system of compliance testing after installation. It also clearly enunciates the effect on the allowable limits where special audible characteristics such as tones, impulses or modulation are apparent. The Tribunal consider the New Zealand standard is the more appropriate acoustic standard for use in the operational control of windfarms and will allow its use for this purpose.*
1998	Victoria, Australia	Cape Bridgewater	Civil	Hislop & Ors v Glenelg SC Hislop & Ors v Glenelg SC	http://www.austlii.edu.au/cgi-bin/sinodisp/au/cases/vic/VICCAT/1998/1138.html?stem=0&synonyms=0&query=wind%20farm	For the wind farm	

Type of Court Case
Environment - A court dedicated to assessing environmental. land and resource usage issues - ERT in Ontario, ERD in South Australia, Environment in NZ
Civil - Civil case in general civil courts including VCAT in Victoria, Australia
Higher -High, Superior or Supreme courts which have general competence and typically unlimited jurisdiction with regard to civil and criminal legal cases.
Utility - utility regulatory panels

Other references
http://envirolaw.com/antiwind-litigation-sight/

ICE THROW

APEX CLEAN ENERGY

GE
Energy

Ice Shedding and Ice Throw – Risk and Mitigation

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Ice Shedding and Ice Throw – Risk and Mitigation

Introduction

As with any structure, wind turbines can accumulate ice under certain atmospheric conditions, such as ambient temperatures near freezing (0°C) combined with high relative humidity, freezing rain, or sleet. Since weather conditions may then cause this ice to be shed, there are safety concerns that must be considered during project development and operation. The intent of this paper is to share knowledge and recommendations in order to mitigate risk.

The Risk

The accumulation of ice is highly dependent on local weather conditions and the turbine's operational state.[2,4] Any ice that is accumulated may be shed from the turbine due to both gravity and the mechanical forces of the rotating blades. An increase in ambient temperature, wind, or solar radiation may cause sheets or fragments of ice to loosen and fall, making the area directly under the rotor subject to the greatest risks[1]. In addition, rotating turbine blades may propel ice fragments some distance from the turbine—up to several hundred meters if conditions are right.[1,2,3] Falling ice may cause damage to structures and vehicles, and injury to site personnel and the general public, unless adequate measures are put in place for protection.

Risk Mitigation

The risk of ice throw must be taken into account during both project planning and wind farm operation. GE suggests that the following actions, which are based on recognized industry practices, be considered when siting turbines to mitigate risk for ice-prone project locations:

- **Turbine Siting:** Locating turbines a safe distance from any occupied structure, road, or public use area. Some consultant groups have the capability to provide risk assessment based on site-specific conditions that will lead to suggestions for turbine locations. In the absence of such an assessment, other guidelines may be used. Wind Energy Production in Cold Climate[6] provides the following formula for calculating a safe distance:

  1.5 * (hub height + rotor diameter)

  While this guideline is recommended by the certifying agency Germanischer Lloyd as well as the Deutsches Windenergie-Institut (DEWI), it should be noted that the actual distance is dependant upon turbine dimensions, rotational speed and many other potential factors. Please refer to the *References* for more resources.

- **Physical and Visual Warnings:** Placing fences and warning signs as appropriate for the protection of site personnel and the public.[4]

- **Turbine Deactivation:** Remotely switching off the turbine when site personnel detect ice accumulation. Additionally there are several scenarios which could lead to an automatic shutdown of the turbine:

  - Detection of ice by a nacelle-mounted ice sensor which is available for some models (with current sensor technology, ice detection is not highly reliable)
  - Detection of rotor imbalance caused by blade ice formation by a shaft vibration sensor; note, however, that it is possible for ice to build in a symmetric manner on all blades and not trigger the sensor[2]
  - Anemometer icing that leads to a measured wind speed below cut-in

- **Operator Safety:** Restricting access to turbines by site personnel while ice remains on the turbine structure. If site personnel absolutely must access the turbine while iced, safety precautions may include remotely shutting down the turbine, yawing to place the rotor on the opposite side of the tower door, parking vehicles at a distance of at least 100 m from the tower, and restarting the turbine remotely when work is complete. As always, standard protective gear should be worn.

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The following are informative papers that address the topic of wind turbine icing and safety. These papers are created and maintained by other public and private organizations. GE does not control or guarantee the accuracy, relevance, timeliness, or completeness of this outside information. Further, the order of the references is not intended to reflect their importance, nor is it intended to endorse any views expressed or products or services offered by the authors of the references.

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GARRAD HASSAN

RECOMMENDATIONS FOR RISK ASSESSMENTS OF ICE THROW AND BLADE FAILURE IN ONTARIO

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1 INTRODUCTION

1.1 Scope and objective

Garrad Hassan Canada Inc. (GHC) has been contracted by the Canadian Wind Energy Association (CanWEA) to (i) provide recommendations for assessing the risk of ice fragments shed from wind turbines striking members of the public in the vicinity of wind farm projects in Ontario and (ii) provide a literature review of wind turbine rotor blade failures based on publicly available information.

The work reported here has been performed in accordance with the proposal provided to CanWEA [1.1]. This report presents the findings of the work undertaken by GHC.

2 WIND TURBINE ICING

Ice can build up on wind turbine rotor blades when appropriate conditions of temperature and humidity exist, as it will on any structure which is exposed to the elements. When a wind turbine is stationary, it is no more likely to suffer from ice accretion than any other large stationary structure such as a building, tree or power line. As for such other structures, accreted ice will eventually be released and fall to the ground.

When a wind turbine is operating, which will typically be when the wind speed at the wind turbine hub height is in the range 4 m/s to 25 m/s, ice can still accrete on the rotor blades in appropriate conditions of temperature and humidity. In this case, observations suggest that higher ice accretion rates occur due to the relative velocity of the rotor blades but that accretion is retarded by the flexing of the blades. Ice fragments which detach from the rotor blades can be thrown from the wind turbine. Any fragments will land in the plane of the wind turbine rotor or downwind.

In situations for which a risk is perceived due to icing of rotor blades, mitigation measures are often taken in terms of automated or (remote) manual shutdown of the wind turbines. It should be noted that remote monitoring and operation of wind farms is now standard in the industry.

Certification requirements detail the load cases which must be used in the design of a wind turbine and these load cases include iced blades in order to ensure that adequate strength is provided in the structure. It is generally accepted in the wind industry that ice build up on the blades of an operating turbine will lead to additional vibration caused by both mass and aerodynamic imbalance. All commercial machines include vibration monitors, which will shut the machine down when vibrations exceed a pre-set level.

As with a large stationary structure, the risk remains of ice forming at a slow rate on the structure and dropping from the stationary turbine. As this thaws, there will be some wind blow effect although that will be small on all but the lightest particles. GHC estimates that only very high winds may cause fragments of any significant mass to be blown beyond 50 m of the base of a modern 2 MW turbine which is stationary. Operating staff will be well briefed on this situation and the risk will be minimal.

Risks associated with an operational turbine are larger than those associated with a stationary one. When a turbine re-starts after a prolonged period of shutdown ice particles may be thrown from the blade. Further ice may form during operation and will eventually also be thrown. Typically there are operational procedures designed to minimise risk to staff which are adopted by projects which include wind turbines which may experience icing.

This report addresses the behaviour of ice thrown from an operating turbine.

3 RECOMMENDED ICE THROW RISK ASSESSMENT METHODOLOGY

3.1 Methodology overview

The assessment methodology recommended is based on that developed by Garrad Hassan and Partners Ltd (GHP) in conjunction with the Finnish Meteorological Institute and Deutsches Windenergie-Institut as part of a research project on the implementation of wind energy in cold climates (WECO) primarily funded by the European Union and also supported, in part, by the United Kingdom Department of Trade and Industry [3.1]. The overall approach is presented schematically in Figure 3.1 and is based on a staged approach:

- Determine the periods when ice accretion on structures is technically possible, based on historical climatic observations.
- Within those periods, determine when the wind speed conditions are within the operational range of the wind turbines.
- Within the resultant periods, exclude those periods when the wind turbines will be shut down automatically by the wind turbine control system or by remote operators.
- Based on an estimate from the above of the amount of icing, use guidelines (see Section 3.2) to arrive at probability of fragments landing at the distances from the turbines which are of interest.
- Estimate probability of members of the public being present within the distances from the turbine which are being considered.
- Arrive at combined probability of members of the public being hit by ice fragments.
- Compare that probability to a suitable benchmark risk – the most commonly used one being the risk of being struck by lightning.

It is considered that the methodology is applicable to wind farm projects in Ontario by considering the proposed turbine type, the terrain of the site and surrounding area, and assumptions for human presence in the surrounding area.

3.2 Guidelines

The guidelines for safety assessments in relation to ice throw were developed by GHP in the WECO project and that work was summarized in a series of conference papers [3.2,3.3,3.4].

The guidelines produced in the WECO project were based on a combination of numerical modelling and observations. Similarly to the WECO project, the calculation methods described in [3.2] have been extended to make estimates of the probability of any particular ice fragment landing in a given square meter area of ground. This is considered to be representative of the risk of a person standing in one particular point being struck. In the absence of field data, an assumption is required on the relative probability of the ice fragment becoming detached as a function of its radial position on the blade, and the azimuthal position of the blade. The following assumptions have been made:

- The fragment is equally likely to become detached at any blade azimuth angle.
- The probability of ice detachment at the tip is three times greater than at the hub, with linear interpolation used for other radial positions.

- Ice fragments have mass of 1 kg and frontal area 0.01 m^2.
- Wind speeds are distributed according to a Rayleigh distribution with a mean of 8 m/s, and there is no correlation between wind speed and the occurrence of icing conditions.
- All wind directions are equally likely, with no correlation between wind direction and the occurrence of icing conditions, and the turbine nacelle is aligned with the wind.
- The turbine rotor speed is zero when the wind speed is outside the operation wind speed range of the wind turbine considered.
- Parameters for the wind turbine considered are:

Wind turbine model	Generic – 2.0 MW
Rotor diameter	80 m
Hub height	80 m
Cut-in wind speed	4 m/s
Cut-out wind speed	25 m/s
Nominal rotor speed (fixed)	15 rpm
Nominal tip speed (fixed)	62.8 m/s

Table 3.1 Wind turbine parameters

A Monte Carlo analysis has been used, in which 100,000 ice fragments are shed from the rotor. The initial radial and azimuthal position and the wind speed and direction conform to the assumed probability distributions. The ranges of the fragments are binned to obtain the distribution of landing probability per unit ground area.

The results are shown in Figure 3.2. This represents the probability, given an ice fragment has been released, that any one ice fragment lands in one square metre of ground area, as a function of distance from the turbine. Clearly the risk per square metre per year is obtained by multiplying by this probability by the probability of a fragment being released, which in turn depends on the number of ice fragments thrown from the turbine per year.

From these results it would appear that there is a critical distance of approximately 220 m from a turbine, at greater distances the probability falls off rapidly. The critical distance can effectively be regarded as a 'safe' distance, beyond which there is negligible risk of injury from ice throw. The critical distance depends mainly on the tip speed of the turbine, not on its size. The maximum tip speeds of commercially available turbines are all quite similar.

In the modelling, further assumptions are required in regard to the aerodynamic properties of ice fragments. These assumptions were verified during the course of the WECO project by measuring the lift and drag characteristics of models of typical ice fragments in wind tunnels. Those coherent fragments collected from various icing events were irregular blocks shed from the leading edge of the rotor blades. Moulds were produced from these and replicas cast for wind tunnel testing. No stable lifting situation was measured leading to a conclusion that the lift coefficient could be ignored. The drag coefficient meanwhile was measured to fall in the same range as was assumed in the modelling described above.

In the EU WECO study [3.4], the observations of ice build-up on rotor blades and fragments shed from rotor blades were gathered from wind farms throughout Europe. The data gathered are presented in Figure 3.3, which shows that fragments typically land within 100 m of the wind turbine. Ice fragments with masses up to 1 kg were found although most were much smaller.

When considering the results above and assuming three categories of icing conditions for this Ontario study, the chart in Figure 3.4 is proposed for use in risk assessment where detailed assessment is required. It will be noted that the critical distance of 220 m referred to above is significantly exceeded in the data presented in Figure 3.4. The curves provided for distances in excess of 250 m have been included on a pragmatic basis to add a level of conservatism at low probability values and are not based purely on the data presented in Figure 3.2.

The results are based on "sample conditions" as listed above. It may be necessary to consider more specific site conditions. For example the actual wind rose could be included. Many turbines are now variable speed but, as a conservative assumption, the example used here uses a fixed speed turbine. In a variable speed turbine the tip speed of the blades is lower than assumed here and hence the distance travelled by any ice is likely to be smaller.

3.3 Example calculations

To demonstrate the recommended methodology, three example calculations are presented:

- Scenario A – Fixed dwelling
- Scenario B – Road
- Scenario C – Individual

They have been designed to represent a typical wind farm project in rural Southern Ontario.

For the purpose of the example calculations, the sites for all three scenarios are represented by the assumptions listed above. Moderate icing conditions (5 days per year) in flat open terrain have been assumed. The relevant distances for each scenario are presented in Figures 3.5 to 3.7. It is also assumed that there are no mitigation strategies as discussed Section 5 in place to prevent an ice throw event from occurring.

The result for each calculation is presented in term of Individual Risk (IR) which is defined in this case as the probability of being struck by ice fragment per year. This value can be compared to other natural hazards such as being struck by lightning. For example, the average annual *per capita* lightning strike rate in the United States is approximately 1 in 600,000 [3.5].

3.3.1 Scenario A – Fixed dwelling

In this scenario, a 100 m^2 dwelling is situated at a distance of 300 m from a turbine, see Figure 3.5. Based on the general assumptions, the following calculation can be made:

- From Figure 3.4 for moderate icing conditions, the risk is approximately 0.00002 strikes per square meter per year for a distance of 300 m.
- This risk is for all wind directions. However we are only concerned with wind directions resulting in a turbine rotor alignment with the dwelling. Assuming that these wind directions occurs 80% of the time during icing conditions, the resulting probability for a 100 m^2 dwelling would be:

  $$0.00002 \times 100\ m^2 \times 0.8 = 0.0016 \text{ strikes per year}$$

- To calculate the IR probability, it is further assumed that the dwelling is always occupied during icing conditions, the dwelling affords no protection to the inhabitant and that there is a

1 in 100 chance that any ice throw event striking the dwelling will result in an individual being struck i.e. the individual's "cross section" is 1 m^2. The resulting IR would be:

$$IR = 0.0016 \times 0.01 = 0.000016 \text{ strikes per year.}$$

This is equivalent to 1 strike per 62,500 years.

3.3.2 Scenario B – Road

In this scenario, a north-south road is situated directly west of a turbine at a minimum distance of 200 m. With this condition, the following calculation can be made:

- From Figure 3.4 for moderate icing conditions, the risk profile on the road can be plotted as presented in Figure 3.8.
- It is assumed in a rural setting that 100 vehicles traveling at 60 kilometer per hour will pass the turbine during the 5 days of icing events. From Figure 3.8, a vehicle would be exposed to hazard for a conservative 600 m segment of the road. Therefore, the fraction of time that a vehicle would be exposed to hazard is:

  $$100 \text{ vehicles} \times 600 \text{ m} / 60 \text{ km/hr} / (5 \text{ days} \times 24 \text{ hours}) = 0.008$$

- Calculating the area weighted average under the risk profile of Figure 3.8 and assuming that wind directions resulting in a turbine rotor alignment with the road occur 80% of the time during icing conditions, the resulting IR for a vehicle with a plan area of 10 m^2 would be:

  $$IR = 0.00016 \times 0.008 \times 0.8 \times 10 \text{ m}^2 = 0.000010 \text{ strikes per year.}$$

  This is equivalent to 1 vehicle strike per 100,000 years

3.3.3 Scenario C – Individual

For this scenario, it is assumed that one ever-present individual is present within 300 m of a turbine and that individual is equally likely to be in any given 1 m^2 within that area but does not impinge within 50 m of the turbine base. It is also assumed that the wind blows in all directions equally during icing conditions when wind speed levels are in the operational range of the wind turbine. With this scenario, the following calculation can be made:

- From Figure 3.4 for moderate icing conditions, the risk profile for distances between 50 m and 300 m can be obtained.
- Given that the area between 300 m and 50 m is approximately 275,000 m^2 and calculating the distance weighted area under the 50 m to 300 m risk profile, the resulting IR probability for an individual with a plan area of 1 m^2 would be:

  $$IR = 0.002 \times (1 \text{ m}^2 / 275{,}000 \text{ m}^2) \times 275{,}000 \text{ m}^2 = 0.002 \text{ strikes per year.}$$

  This is equivalent to 1 strike in 500 years.

3.4 Additional factors to consider

While the above example scenarios are indicative, it is recommended that the importance of the following additional factors be considered with any risk assessment of ice throw hazards:

- Accounting for the presence of individual in the unpleasant weather conditions necessary for icing conditions;
- Specific parameters of the wind turbine model considered in the assessment;
- Presence of tree coverage or other structures that may provide shelter;
- Frequency of the wind direction in relation to the risk area under assessment;
- Terrain slope – may be a significant factor if a turbine is sited on an elevated hill or ridge; and
- Implementation of control mitigation strategies as discussed in Section 5.

4 ICE THROW OBSERVATIONS IN ONTARIO

To offer further support to the methodology described in the previous section for Ontario, it is recommended that a publicly available data base of ice throw observations from wind farms in Ontario is produced. A suggested wind farm operator survey has been provided in the Appendix for this purpose.

The only known recorded and publicly available example of such observations in Ontario is from an existing Tacke TW600 wind turbine near Kincardine. The operator monitored the operation of that turbine since its installation in December 1995 until March 2001 [4.1]. In that period, approximately 1000 inspections were made, a manual note was made on each occasion. In these notes, some form of ice build-up on the wind turbine was recorded on 13 occasions during the December 1995 and March 2001 observation period, as reproduced in Table 4.1.

Record date	Event date	Comment
1 Apr 2001	2 Mar 2001	"Minor icing event, only a few pieces of ice on the ground"
1 Apr 1999	3 Mar 1999	"One icing event, found only a few pieces of ice on ground"
1 Jan 1999	Not noted	"...minor icing on one day"
10 Jan 1998	Not noted	"There was some ice build up on blades during a freezing rain event, all ice fell off and unit ran OK" "Many ice pieces, largest piece was 12x12x2 inches, pieces up to 100 m from tower"
17 Mar 1997	13-14 Mar 1997	"Ice storm, winds up to 20m/s, ice on blades ..... after 4 hrs, the ice got off slowly ..... found only a few pieces of ice on the ground"
1 Mar 1997	Feb 1997	"5 icing events ... only a few pieces on ground"
23 Feb 1996	23 Feb 1996	"About 1 ton of ice on ground. During my weekly inspection, found many pieces of ice at base of windmill. Pieces of ice had same curve as blade therefore these pieces of ice came from the leading edge of the blade. Estimated about 1000 pieces on ground. The largest pieces were 5 inches long 2 inches thick and 2 inches wide. The pieces were scattered up to 100 meters from base of windmill in same direction as blade arms were pointing – this was in the north-south direction as the wind was coming from the east. Most pieces were found within 50 meters from tower base"
27 Jan 1996	27 Jan 1996	"Ice on wings .... Found some ice pieces on ground"
14 Dec 1995	14 Dec 1995	"Freezing rain but good wind ... anemometer slowed down, ice build up ...found a few pieces of ice on ground"

Table 4.1 Observations of icing at Tacke TW600 wind turbine

There was no event recorded by the operator in which the ice that was thrown from the Tacke TW600 turbine struck any property or person.

5 TYPICAL CONTROL MITIGATION STRATEGIES

While the risk to the public from ice throws can be assessed as demonstrated by the worked examples in Section 3.3, in a situation where a significant risk to the public or operational staff due to ice throw is believed to exist, the following control mitigation strategies are suggested:

- Curtailing operation of turbines during periods of ice accretion.
- Implementing special turbine features which prevent ice accretion or operation during periods of ice accretion.
- The use of warning signs and/or gated access ways alerting anyone in the area of risk.
- Through established protocols and procedures, operational staff should be aware and take appropriate action when the conditions likely to lead to ice accretion on the turbine are present which could lead to the risk of ice falling from the rotor in areas of risk.

In the planning stage, re-siting of the turbines to remove them from areas of risk should also be considered where possible.

Reduction of icing on a wind turbine operating under icing conditions can significantly be improved by using blade heating system to avoid ice accretion on blades. Such an approach is however prohibitively expensive and is not used on a commercial basis.

5.1 Automated ice detection systems

Reliable detection of icing conditions in order to allow automated turbine curtailment and/or activation of blade heating systems during unattended operation is commonly desired by owners.

While ice detection systems are a continued area of research, ice detectors are commercially being used for this purpose. The most widely available and common type found in practice are ultrasonic ice detectors which detect icing with an ultrasonically-vibrating probe (frequencies between 40-70 kHz). Ice adhering to the probe decreases its resonant frequency due to the increase in mass.

In practice, it is important to measure not only whether there is ice on a detector, but also to monitor the persistence of icing conditions. Therefore a device having heating elements which are switched on after ice accumulation is detected beyond a certain threshold is also desirable. The accumulated ice is quickly melted, the sensor cools in a few seconds, and the device is ready to measure ice again. The frequency of heating can roughly be called an "icing rate", consequently these types of devices are sometimes marketed as "icing rate sensors".

Ice detectors are typically mounted on the nacelle of a turbine and monitored by the wind farm control system, trigger an automatic or remote manual shutdown of the wind farm control system in the event that icing conditions are detected. Given the flexing action of the blades experience suggests that the nacelle icing is more common than blade icing and hence such an approach is conservative.

In addition to ice detectors, the use of web cams, indirect signals such as power curve "plausibility", ratio between heated and unheated anemometer readings, and audible performance of the blades have been proposed. While these alternative methods or combinations of these

methods may increase reliability and redundancy of ice detection systems, they largely remain at the early development stage for commercial use.

6 LITERATURE REVIEW OF ROTOR BLADE FAILURES

GH has undertaken a review of publicly-available literature on turbine failures, in particular turbine rotor failures resulting in full or partial blade throws.

6.1 Publicly available lists of wind turbine failure events

A recent report prepared by the California Wind Energy Collaborative (CWEC) in November 2006 [6.1] provides a brief literature review of turbine failures rates and provides recommendations for assessing the risk of full or partial blade throws.

Such events are very rare and hence data describing them are scarce. CWEC states that reporting on turbine failures is very limited providing very few publicly available accounts. The main types of blade failures are listed by CWEC as:

- Full blade failure at root connection,
- Partial blade failure from lightning damage, defect or extreme load buckling,
- Failure at outboard aerodynamic device, and
- Failure from tower strike.

Factors attributed to these failures are:

- Unforeseen environmental events outside the design envelope,
- Incorrect design for ultimate or fatigue loads,
- Poor manufacturing quality,
- Failure of turbine control/safety system, and
- Human error.

Most failures are actually reported to be a combination of the above factors and it is reported that the probabilities of some failure events are highly correlated with each other [6.1].

The main source listed in the CWEC report [6.1] is a Dutch Handbook [6.2] which compiles the information of two large databases of wind turbines in Denmark and Germany covering turbine operation from the 1980s until 2001. The authors of the handbook analyzed the data and recommended the following risk values for blade failure rates:

- Full blade failure at nominal rotor speed – 1 in 2,400 turbines per year
- Full blade failure at mechanical breaking (~1.25 times nominal rotor speed) – 1 in 2,400 turbines per year
- Full blade failure at mechanical breaking (~2.0 time nominal rotor speed) – 1 in 20,000 turbines per year
- Failure of tip or piece of blade – 1 in 4,000 turbines per year

Documented blade failures and distances were also reported in the handbook with the maximum distance reported for an entire blade as 150 m and for a blade fragment 500 m.

The handbook authors have compared these recommended blade failure rates to earlier ones developed by European agencies in the earlier 1990s, and state that the overall blade failure rate has declined by a factor of three. The authors of [6.2] have commented that "with the maturity of the industry blade failures will continue to decrease".

The most recent list of publicly available wind turbine accident reports, last updated in February 2007, has been complied by the Caithness Windfarms Information Forum (CWIF) [6.3]. The list states that from the 257 accidents listed since 2000, 74 were reported as blade failures.

6.2 General comments

GH considers that the failure rate values recommended by the Dutch Handbook [6.3] are particularly conservative in the context of current-day commercial wind turbines as the various root-causes of blade failure have been continuously addressed through developments in best practice in design, testing, manufacture and operation. Much of this development has been captured in the IEC standards series with which all current large wind turbines comply. Background on the turbine certification process in provided in Appendix 2. Use of the Handbook values for present day turbines can therefore be considered as inappropriate.

The reduction in blade failures referred to in the above reports coincides with the widespread introduction of turbine design certification and type approval. In addition to certifying compliance with standards, this process requires full scale strength testing of every certified design of turbine blade. In addition, it typically requires a dynamic test that simulates the complete life loading on the blade. The certification body will also perform a quality audit of the blade manufacturing facilities and perform strength testing of construction materials. This approach has effectively eliminated blade design as a root cause of failures.

The main causes of blade failure are now a human interference with a control system leading to an over-speed situation, a lightning strike or a manufacturing defect in the blade. The latter cause does not often lead to detachment of blade fragments.

Turbine control systems are the subject of rigorous specification in the design standards for wind turbines (IEC 61400-1) and exhaustive analysis in the certification process, hence most systems operate in a safe and reliable manner. Turbines with industry certification must have a safety system completely independent of the control system. The safety system must also have two mutually independent braking systems capable of bringing the rotor speed under control in the event of loss of reaction torque – which happens in the event of failure of the utility grid connection. Usually the blades pitch to remove the aerodynamic driving torque and provide a braking torque in its place, redundancy is usually provided through the provision of two separate pitching systems and some times it is provided in the form of a mechanical brake applied to the high speed shaft. In the event of a failure in one system, the other system must be able to control the rotor speed.

Anecdotal information now suggests that the most common cause of a control system failure is human error; where an operator makes an unauthorized adjustment. Many manufacturers have recognized this risk and are now limiting the adjustments that can be made in the field.

Lightning protection systems for wind turbines have developed significantly over the past decade and best practice has been captured in industry standards to which all modern turbines comply. This has led to a significant reduction in events where lightning causes structural damage.

The occurrence of structural manufacturing defects in rotor blades has also diminished significantly due to improved experience and quality control in the industry, centered on a small number of companies who make blade manufacture their main or sole business. Design practice has also evolved to improve structural margins against any manufacturing deficiencies. Even in the rare event of blade failure in modern machines, it is much more likely that the damaged structure will remain attached to the turbine than to separate.

It is considered that the above developments have substantially reduced the probabilities of blade failure from those represented in the Dutch Handbook [6.3]. This has been necessitated by the increasing trend of locating wind turbines in very close proximity to population – most notably in Northern Europe. GHC is not aware of any member of the public having been injured by a blade or blade fragment from a wind turbine.

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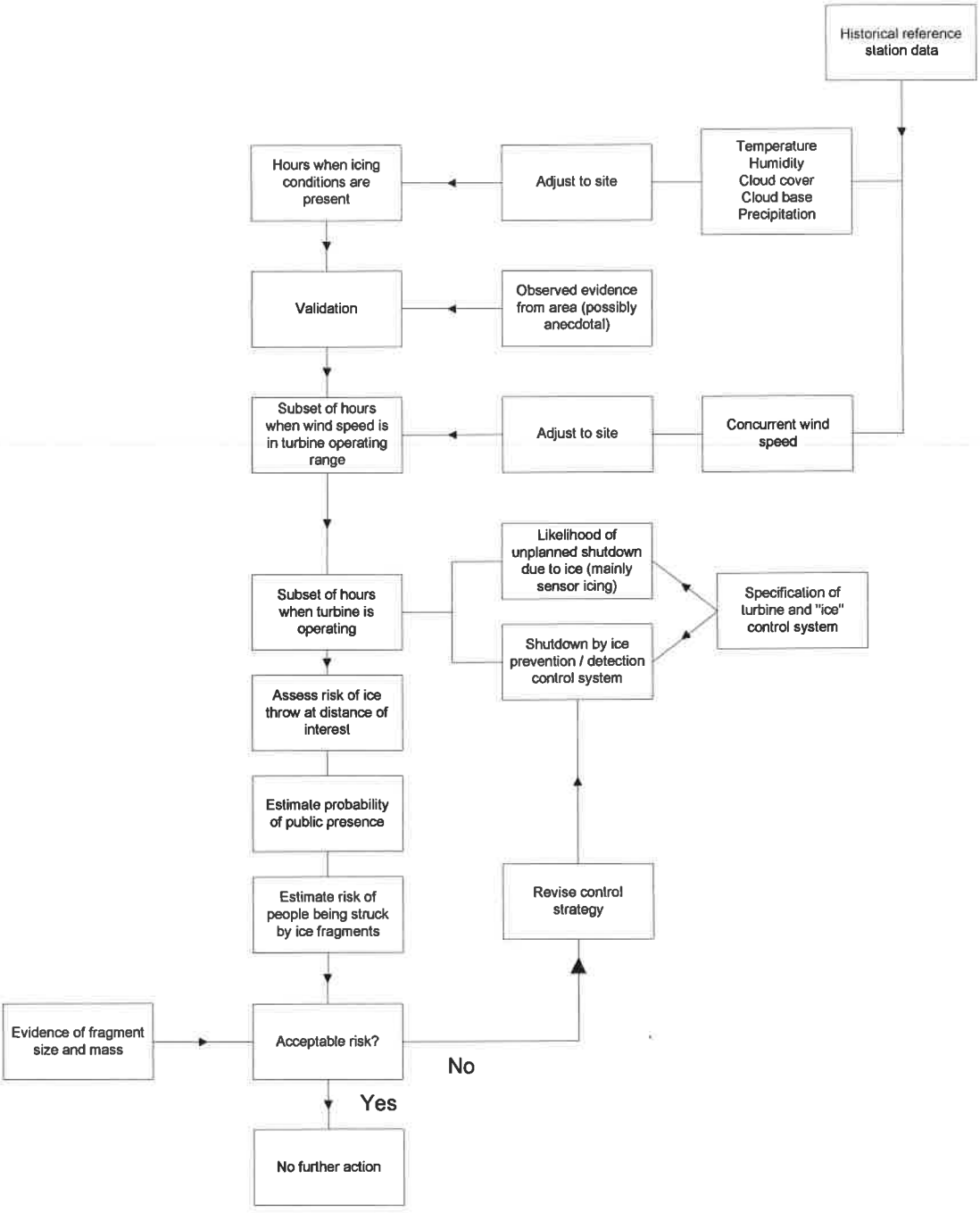

Figure 3.1 Ice throw risk assessment procedure

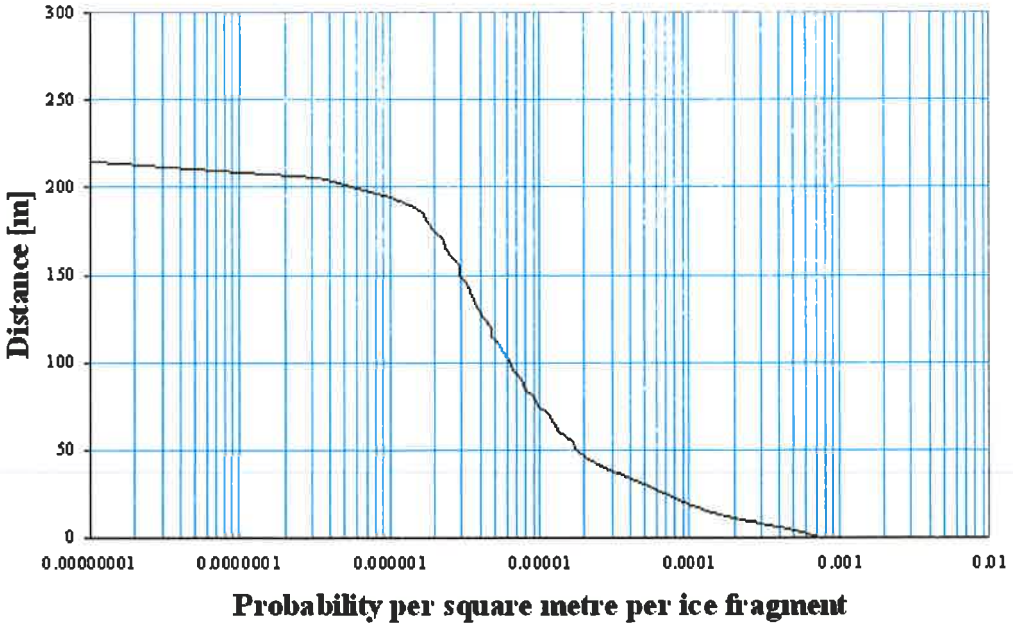

Figure 3.2 Calculated probability of ice fragment throw distances

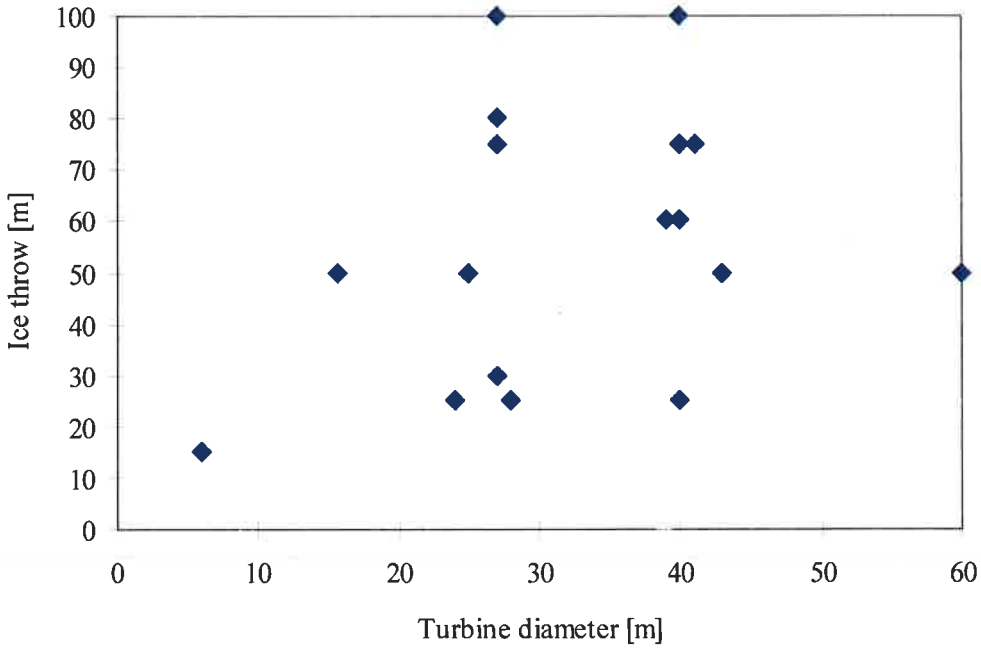

Figure 3.3 Recorded ice throw data (from [3.4])

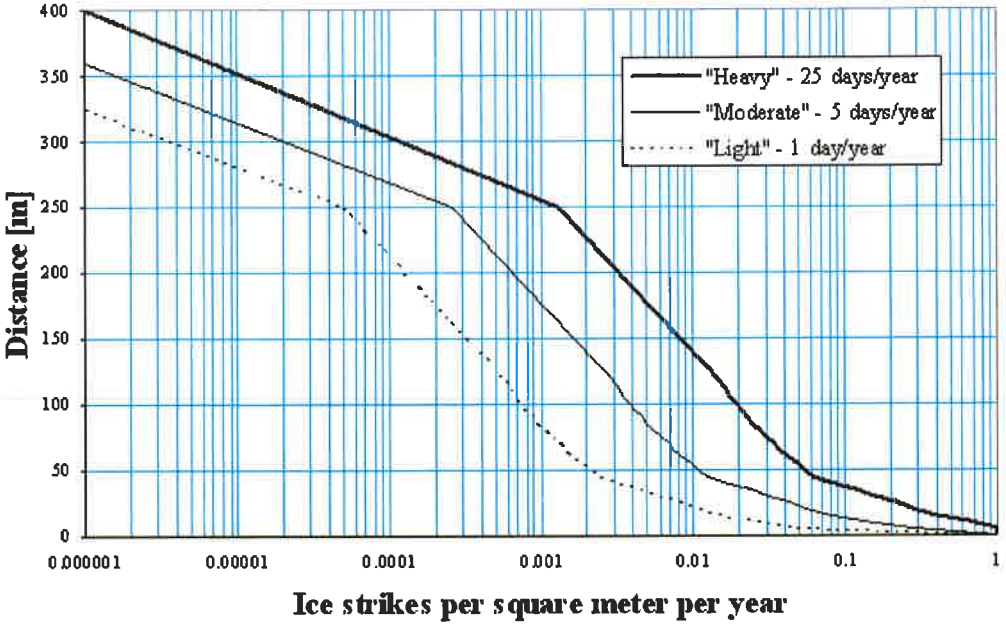

Figure 3.4 Recommended probability for ice fragment strikes in Ontario

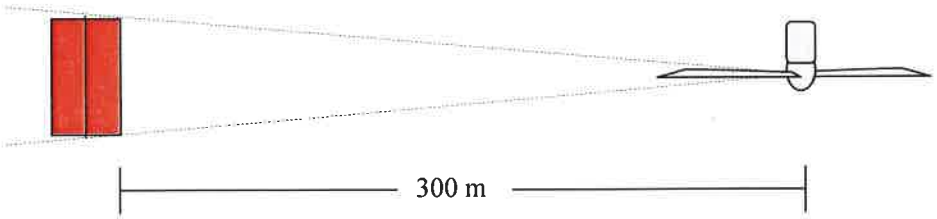

Figure 3.5 Scenario A – Fixed dwelling

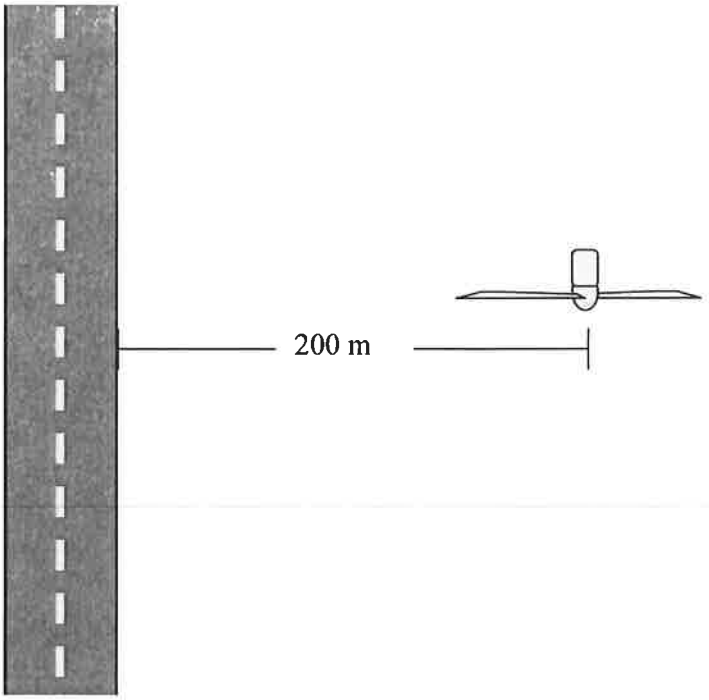

Figure 3.6 Scenario B – Road

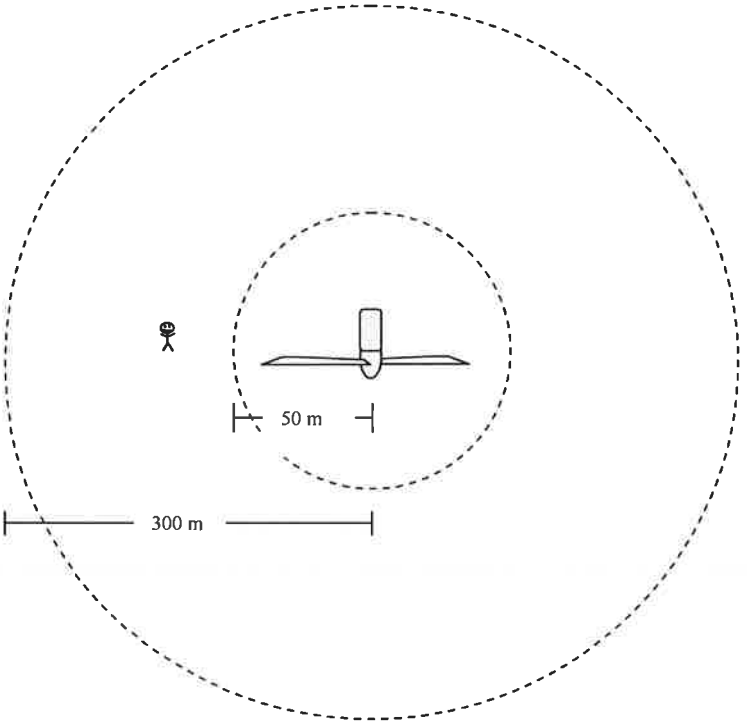

Figure 3.7 Scenario C – Individual

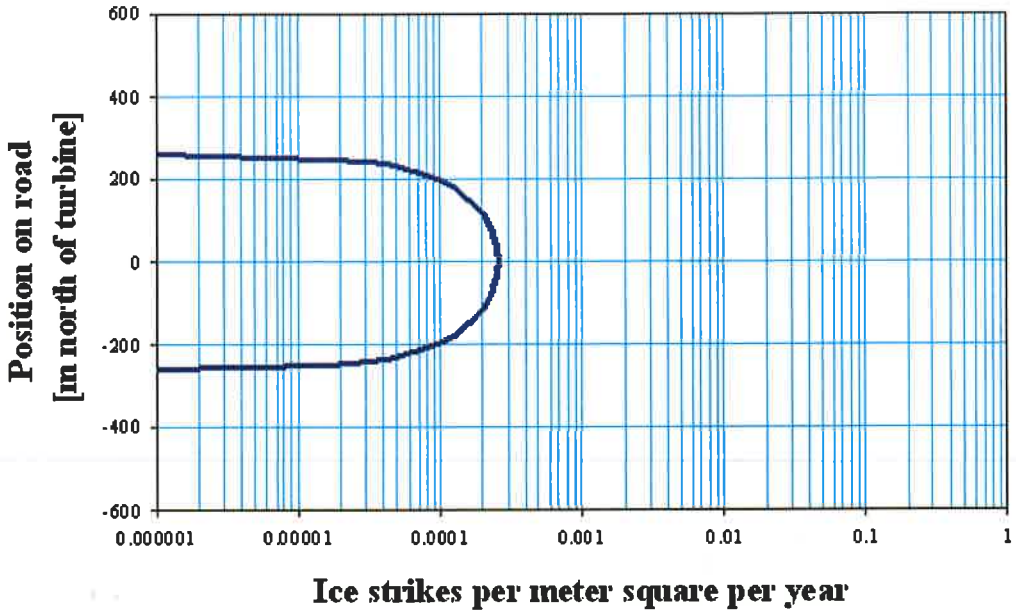

Figure 3.8 Risk profile for Scenario B

APPENDIX I

Wind farm operator survey

ONTARIO WIND TURBINE ICING EVENT SURVEY

GENERAL POJECT INFORMATION **Date:** _____

Site name: _____

Location: _____

Elevation: _____ (meters or feet above sea level)

Terrain: ☐ Lakeshore ☐ Flat ☐ Hilly ☐ Forested (tick all that apply)

Turbine type: _____ Cold weather package? ☐ Yes / ☐ No

Number of turbines: _____ Heated nacelle anemometers? ☐ Yes / ☐ No

Number of winter seasons: _____ Blade heating system? ☐ Yes / ☐ No

TYPICAL ICING EVENTS

Number of icing events per year: ☐ none ☐ 1 to 5 ☐ 5 to 10 ☐ 10 to 25 ☐ > 25

Typical duration of events: ☐ < 1 hour ☐ 1 to 5 hours ☐ 5 to 12 hours ☐ > 12 hours ☐ Unknown

Most frequent type of ice found: ☐ Glaze (clear) ☐ Rime (white) ☐ Other: _____

Condition(s) for typical icing events: ☐ Freezing Rain ☐ Fog ☐ Both ☐ Other: _____

Typical turbine reaction during icing: ☐ Shutdown ☐ Fault only ☐ No reaction ☐ Other: _____

MOST SIGNIFICANT ICING EVENT

Approximate date: Year: _____ Month: _____ Day: _____ Time: _____

Duration: ☐ < 1 hour ☐ 1 to 5 hours ☐ 5 to 12 hours ☐ > 12 hours ☐ Unknown

Type of ice found: ☐ Glaze (clear) ☐ Rime (white) ☐ Other: _____

Condition(s) for icing event: ☐ Freezing Rain ☐ Fog ☐ Both ☐ Other: _____

Turbine reaction during icing event: ☐ Shutdown ☐ Fault only ☐ No reaction ☐ Other: _____

ICE THROW

Have you witnessed ice thrown from a turbine? ☐ Yes / ☐ No

Have you ever found ice fragment(s) around a turbine? ☐ Yes / ☐ No

If YES to either question:

How far was the ice thrown? _____ (meters or feet)

Size of ice fragment: _____

Approximate weight: ☐ < 250 g ☐ 250g -1kg ☐ > 1kg ☐ Unknown

Additional comments: _____

_____

_____

APPENDIX II

Wind turbine certification process

The wind industry de facto standard calls for a turbine to be certified by a recognized certification agency. There are a couple of different types of certifications that are commonly referred to by manufacturers selling into North America:

- Statement of Compliance for Design Assessment of a turbine in compliance with an edition of IEC 61400-1 rules for safe design.
- Type certificate according to IEC WT01:2001

The "Type" certification scheme according to IEC WT01:2001 is divided into three modules. It is possible to obtain certification for each of these modules. The certificates are normally called Statements of Compliance and a Type certification includes a Statement of Compliance for Design Assessment.

The Design Assessment is a thorough review of the design documentation from the turbine manufacturer carried out by the selected certification agency. The design documentation must cover the whole turbine. When evaluating the certification of a turbine one should note the following:

- A Type certification is far more comprehensive than a Design Assessment and therefore Type certification is to be preferred.
- The certification body has to be accredited to perform certification in accordance with the standard used.
- In some cases there are a number of conditions to a given certification. It can more or less undermine the value of the certification.

The Statement of Compliance and associated verification report are issued after review of the machine design using specified components. In order to maintain a valid certificate the machines delivered to site must consist of an assembly of these components. The turbine supplier cannot vary these components and maintain certification. It is therefore important to check that the machines delivered are, indeed, consistent with the certificate and hence with the specification. It is also important to establish, and to check during the manufacturing process, that the turbines delivered are consistent with the certified specification.

This procedure has to be followed throughout the life of the machine. The providers of operation and maintenance service must either ensure that all components used for repair or enhancement are in accordance with the original certification or have the certification modified to reflect any alternative components.

The certification process also requires the inspection of the wind turbine on a periodic basis. This would be generally every two years but this may be extended in certain circumstances. Such inspections should include a detailed inspection of the blades.

PROPERTY VALUES

APEX CLEAN ENERGY

WIND ENERGY AND PROPERTY VALUES

As the development of utility-scale wind energy projects has become more prevalent in this country, concerned communities have asked how these projects would affect their property values. Researchers have been working hard to scientifically answer this question. In 2013 the Lawrence Berkeley National Laboratory (LBNL) completed the most extensive study to date on property transactions near wind farms. Their conclusion?

"...The core results of our analysis consistently show no sizable statistically significant impact of wind turbines on nearby property values."

- 2013 Study by Lawrence Berkley National Laboratory

About the Study:

Researchers analyzed 51,276 home sales near 67 wind farms in 27 counties across nine U.S. states.

- All homes were within 10 miles of wind facilities
- 1,198 sales were within 1 mile of a turbine
- 331 sales were within 1/2 mile of a turbine
- Data was collected before, during and after wind farm construction

Good News for Wind Farmers

Regardless of the type or size of wind turbine studied, researchers find no statistical evidence that home values near turbines are affected before, during or after construction.

The study data shows that statistically, even homes within ½ mile of a wind turbine are not affected by its presence.

According to rural appraisers, farm acreage upon which turbines are sited often increases in value to account for the new stream of steady, long-term income the property generates through the harvesting of the wind.

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APEX CLEAN ENERGY

Relationship between Wind Turbines and Residential Property Values in Massachusetts

A Joint Report of University of Connecticut and Lawrence Berkeley National Laboratory

January 9, 2014

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Lawrence Berkeley National Laboratory

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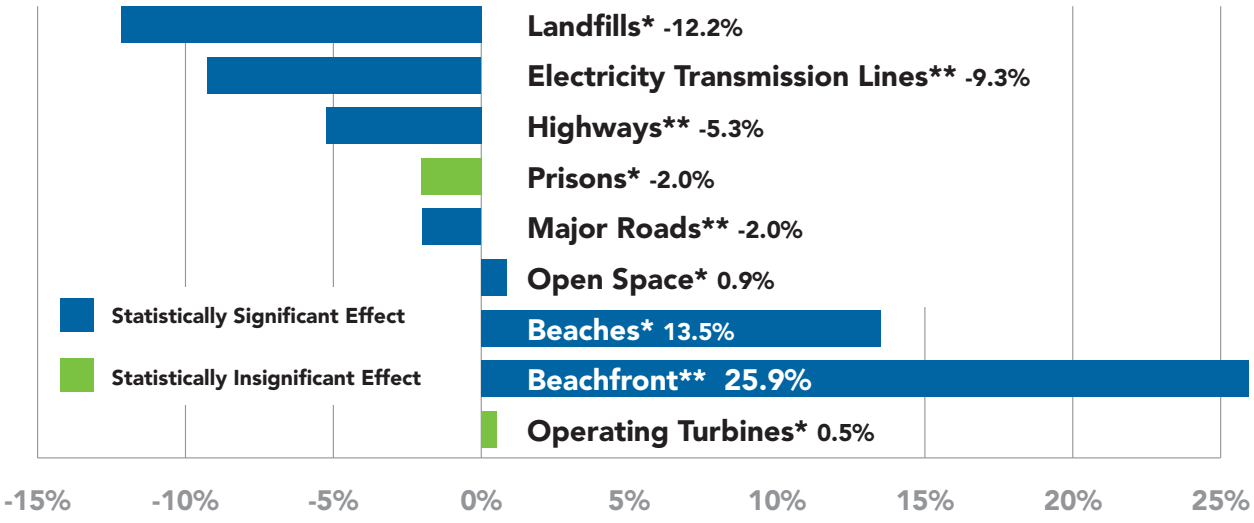
EXECUTIVE SUMMARY

This study investigates a common concern of people who live near planned or operating wind developments: How might a home's value be affected by the turbines? Previous studies on this topic, which have largely coalesced around non-significant findings, focused on rural settings. Wind facilities in urban[1] locations could produce markedly different results. Nuisances from turbine noise and shadow flicker might be especially relevant in urban settings, where negative features, such as landfills or high voltage utility lines, have been shown to reduce home prices. To determine if wind turbines have a negative impact on property values in urban settings, this report analyzed more than 122,000 home sales, between 1998 and 2012, that occurred near the current or future location of 41 turbines in densely-populated Massachusetts communities.

The results of this study do not support the claim that wind turbines affect nearby home prices. Although the study found the effects from a variety of negative features (such as electricity transmission lines and major roads) and positive features (such as open space and beaches) generally accorded with previous studies, the study found no net effects due to the arrival of turbines in the sample's communities. Weak evidence suggests that the announcement of the wind facilities had a modest adverse impact on home prices, but those effects were no longer apparent after turbine construction and eventual operation commenced. The analysis also showed no unique impact on the rate of home sales near wind turbines. These conclusions were the result of a variety of model and sample specifications detailed later in this report.

Figure 1: Summary of Amenity, Disamenity and Turbine Home Price Impacts



*Distance to MA Homes: * within 1/2 mile; ** within 500 feet*

1 The term "urban" in this document includes both urban and suburban areas.

OVERVIEW

Wind power generation has grown rapidly in recent decades. In the United States, wind development centered initially on areas with relatively sparse populations in the Plains and West. Increasingly, however, wind development is occurring in more populous, urbanized areas, prompting additional concerns about the effects of wind turbine construction on residents in those areas.

One important concern is the potential for wind turbines to create a "nuisance stigma"—due to turbine-related noise, shadow flicker, or both—that reduces the desirability and thus value of nearby homes. Government officials who are called on to address this issue need additional reliable research to inform regulatory decisions, especially for understudied populous urban areas. Our study helps meet this need by examining the relationship between home prices and wind facilities in densely-populated Massachusetts.

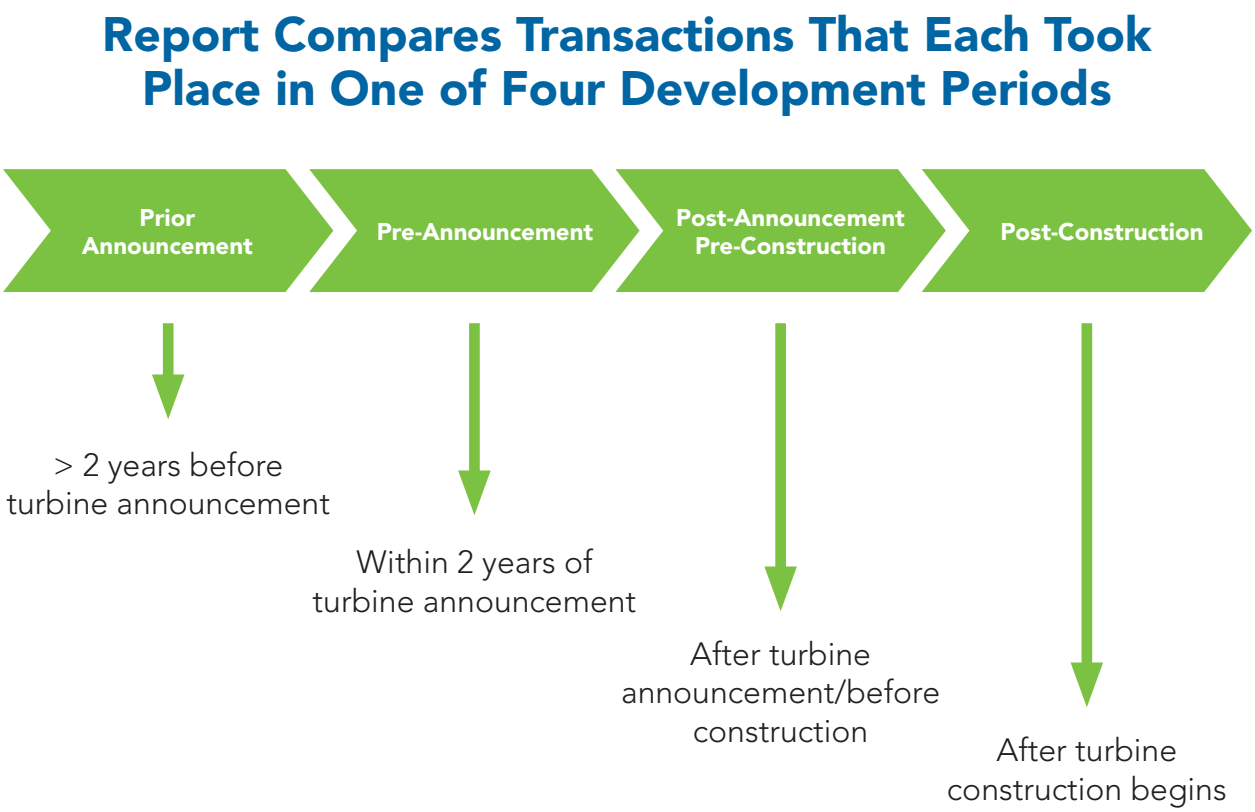
A variety of methods can be used to explore the effects of wind turbines on home prices. Statistical analysis of home sales, using a hedonic model, is the most reliable methodology because it (a) uses actual housing market sales data rather than perceptions of potential impacts; (b) accounts for many of the other, potentially confounding, characteristics of the home, site, neighborhood and market; and (c) is flexible enough to allow a variety of potentially competing aspects of wind development and proximity to be tested simultaneously. Previous studies using this hedonic modeling method largely have agreed that post-construction home-price effects (i.e., changes in home prices after the construction of nearby wind turbines) are either relatively small or sporadic. A few studies that have used hedonic modeling, however, have suggested significant reductions in home prices after a nearby wind facility is announced but before it is built (i.e., post-announcement, pre-construction) owing to an "anticipation effect." Previous research in this area has focused on relatively rural residential areas and larger wind facilities with significantly greater numbers of turbines.

This previous research has done much to illuminate the effects of wind turbines on home prices, but a number of important knowledge gaps remain. Our study helps fill these gaps by exploring a large dataset of home sales occurring near wind turbine locations in Massachusetts. We analyze 122,198 arm's-length single-family home sales, occurring between 1998 and 2012, within 5 miles of 41 wind turbines in Massachusetts. The home sales analyzed in this study occurred in one of four periods based on the development schedule of the nearby turbines (see Figure 2).[2] To estimate the effect proximity to turbines has on home sale prices, we employ a hedonic pricing model in combination with a suite of robustness tests[3] that explore a variety of different model specifications and sample sets, organized around the following five research questions:

2 The analysis focuses on the 41 turbines in Massachusetts that are larger than 600 kilowatt and that were operating as of November 2012.

3 These tests included a comparison of a "base" model to a set of different models, each with slightly different assumptions, to explore the robustness of the study's findings.

Figure 2: Wind Turbine Development Periods Studied



Q1) Have wind facilities in Massachusetts been located in areas where average home prices were lower than prices in surrounding areas (i.e., a "pre-existing price differential")?

Q2) Are post-construction (i.e., after wind-facility construction) home price impacts evident in Massachusetts and how do Massachusetts results contrast with previous results estimated for more rural settings?

Q3) Is there evidence of a post-announcement/ pre-construction effect (i.e., an "anticipation effect")?

Q4) How do impacts near turbines compare to the impacts of amenities and disamenities also located in the study area, and how do they compare with previous findings?

Q5) Is there evidence that houses near turbines that sold during the post-announcement and post-construction periods did so at lower rates (i.e., frequencies) than during the pre-announcement period?

The study makes five major unique contributions:

1. It uses the largest and most comprehensive dataset ever assembled for a study linking wind facilities to nearby home prices.[4]

2. It encompasses the largest range of home sale prices ever examined.[5]

3. It examines wind facilities in urban areas (with relatively high-priced homes), whereas previous analyses have focused on rural areas (with relatively low-priced homes).

4. It largely focuses on wind facilities that contain fewer than three turbines, while previous studies have focused on large-scale wind facilities (i.e., wind farms).

5. Our modeling approach controls for seven environmental amenities and disamenities in the study area, allowing the effect of wind facilities to be compared directly to the effects of these other factors.

The models perform exceptionally well given the volatility in the housing market during the study period, with an adjusted-R^2 of approximately 0.80[6] and highly statistically significant[7] and appropriately signed controlling parameters (e.g., square feet, acres, and age of home at the time of sale). The amenity and disamenity variables (proximity to beaches, open space, electricity transmission lines, prisons, highways, major roads, and landfills) are significant in a large portion of the models and appropriately signed—indicating that the models discern a strong relationship between a home's environment and its selling price—and generally accord with the results of previous studies. To test whether the results of the analysis would change if the model was specified in a different way, or run using a differently-specified dataset, we ran a suite of robustness tests. The results generated from the robustness tests changed very little, suggesting that our approach is not dependent on the model specification or the data selection.

The results do not support the claim that wind turbines affect nearby home prices. Despite the consistency of statistical significance with the controlling variables, statistically significant results for the variables focusing on proximity to operating turbines are either too small or too sporadic to be apparent. Post-construction home prices within a half mile of a wind facility are 0.5% higher than they were more than 2 years before the facility was announced (after controlling for

4 Four of the most commonly cited previous studies (Carter, 2011; Heintzelman and Tuttle, 2012; Hinman, 2010; and Hoen et al., 2011) analyzed a *combined total* of 23,977 transactions, whereas the present study analyzes more than five times that number.

5 Existing studies analyzed the impact of wind turbines on homes with a median price of less than $200,000, whereas the current study examines houses with a median price of $265,000 for the 122,198 observations located within 5 miles of a wind turbine (with values ranging from $40,200 to $2,495,000).

6 In statistics, the coefficient of determination, denoted R^2 (pronounced "R squared"), indicates how well data points fit a line, curve or, in our case, a regression estimation. An R^2 of 1 indicates that the regression line perfectly fits the data.

7 Statistical significance allows one to gauge how likely sample data are to exhibit a definitive pattern rather than, instead, have occurred by chance alone. Significance is denoted by a *p*-value (or "probability" value) which can range between 0 and 1. A very low *p*-value, for example <0.001, is considered highly unlikely (in this case with a probability of less than 0.1%) to have occurred by chance. In general, an appropriate *p*-value is chosen by the researchers consistent with the area of research being conducted, under which results are considered "significant" and over which are considered "non-significant". For the purposes of this research, a *p*-value of 0.10 or below is considered "statistically significant", with *p*-values between 0.10 and 0.05 being "weakly statistically significant", between 0.05 and 0.01 being "significant", and below 0.01 being "highly statistically significant".

What Is a Hedonic Pricing Model?

Hedonic pricing models are frequently used by economists and real estate professionals to assess the impacts of house and community characteristics on property values by investigating the sales prices of homes. A house can be thought of as a bundle of characteristics (e.g., number of square feet, number of bathrooms, the size of the parcel). When a price is agreed upon by a buyer and seller there is an implicit understanding that those characteristics have value. When data from a large number of residential transactions are available, the individual marginal contribution to the sales price of each characteristic for an average home can be estimated with a hedonic regression model. Such a model can statistically estimate, for example, how much an additional bathroom adds to the sale price of an average home. A particularly useful application of the hedonic model is to value non-market goods—goods that do not have transparent and observable market prices. For this reason, the hedonic model is often used to derive value estimates of amenities such as wetlands or lake views, and disamenities such as proximity to and/or views of high voltage transmission lines, roads, cell phone towers, landfills. It should be emphasized that the hedonic model is not typically designed to appraise properties (i.e., to establish an estimate of the market value of one home at a specified point in time) as would a bank appraisal, which would generally be only applicable to that particular home. Instead, the typical goal of a hedonic model is to accurately estimate the marginal contribution of individual or groups of characteristics across a set of homes, which, in general, allows stakeholders to understand if widely applicable relationships exist.

market inflation/deflation). This difference is not statistically significant. Post-announcement, pre-construction home prices within a half mile are 2.3% lower than their pre-announcement levels (after controlling for inflation/deflation), which is also a non-significant difference, though one of the robustness models suggests weak evidence that wind-facility announcement reduced home prices. An additional tangential, yet important, result of the analysis is the finding of a statistically significant "pre-existing price differential": prices of homes that sold more than 2 years before a future nearby wind facility was announced were 5.1% lower than the prices of comparable homes farther away from the future wind location. This indicates that wind facilities in Massachusetts are associated with areas where land values are lower than the surrounding areas, and, importantly, this "pre-existing price differential" needs to be accounted for in order to correctly measure the "post construction" impact of the turbines. Finally, our analysis finds no evidence of a lower rate (i.e., frequency) of home sales near the turbines.

As discussed in the literature review, the effects of wind turbines may be somewhat context specific. Nevertheless, the stability of the results across models and across subsets of the data, and the fact that they agree with the results of existing literature, suggests that the results may be generalizable to other U.S. communities, especially where wind facilities are located in more urban settings with relatively high-priced homes. These results should inform the debate on actual impacts to communities surrounding turbines. Additional research would augment the results of this study and previous studies, and our report concludes with recommendations for future work.

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A Spatial Hedonic Analysis of the Effects of Wind Energy Facilities on Surrounding Property Values in the United States

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Technologies Division**

August 2013

Download from http://emp.lbl.gov/sites/all/files/lbnl-6362e.pdf

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A Spatial Hedonic Analysis of the Effects of Wind Energy Facilities on Surrounding Property Values in the United States

Prepared for the

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Wind and Water Power Technologies Office
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Abstract

Previous research on the effects of wind energy facilities on surrounding home values has been limited by small samples of relevant home-sale data and the inability to account adequately for confounding home-value factors and spatial dependence in the data. This study helps fill those gaps. We collected data from more than 50,000 home sales among 27 counties in nine states. These homes were within 10 miles of 67 different wind facilities, and 1,198 sales were within 1 mile of a turbine—many more than previous studies have collected. The data span the periods well before announcement of the wind facilities to well after their construction. We use OLS and spatial-process difference-in-difference hedonic models to estimate the home-value impacts of the wind facilities; these models control for value factors existing before the wind facilities' announcements, the spatial dependence of unobserved factors effecting home values, and value changes over time. A set of robustness models adds confidence to our results. Regardless of model specification, we find no statistical evidence that home values near turbines were affected in the post-construction or post-announcement/pre-construction periods. Previous research on potentially analogous disamenities (e.g., high-voltage transmission lines, roads) suggests that the property-value effect of wind turbines is likely to be small, on average, if it is present at all, potentially helping to explain why no evidence of an effect was found in the present research.

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1. Introduction

In 2012, approximately 13 gigawatts (GW) of wind turbines were installed in the United States, bringing total U.S. installed wind capacity to approximately 60 GW from more than 45,000 turbines (AWEA, 2013). Despite uncertainty about future extensions of the federal production tax credit, U.S. wind capacity is expected by some to continue growing by approximately 5–6 GW annually owing to state renewable energy standards and areas where wind can compete with natural gas on economics alone (Bloomberg, 2013); this translates into approximately 2,750 turbines per year.[1] Much of that development is expected to occur in relatively populated areas (e.g., New York, New England, the Mid-Atlantic and upper Midwest) (Bloomberg, 2013).

In part because of the expected wind development in more-populous areas, empirical investigations into related community concerns are required. One concern is that the values of properties near wind developments may be reduced; after all, it has been demonstrated that in some situations market perceptions about an area's disamenities (and amenities)[2] are capitalized into home prices (e.g., Boyle and Kiel, 2001; Jackson, 2001; Simons and Saginor, 2006). The published research about wind energy and property values has largely coalesced around a finding that homes sold after nearby wind turbines have been constructed do not experience statistically significant property value impacts. Additional research is required, however, especially for homes located within about a half mile of turbines, where impacts would be expected to be the largest. Data and studies are limited for these proximate homes in part because setback requirements generally result in wind facilities being sited in areas with relatively few houses, limiting available sales transactions that might be analyzed.

This study helps fill the research gap by collecting and analyzing data from 27 counties across nine U.S. states, related to 67 different wind facilities. Specifically, using the collected data, the study constructs a pooled model that investigates average effects near the turbines across the sample while controlling for the local effects of many potentially correlated independent variables. Property-value effect estimates are derived from two types of models: (1) an ordinary

[1] Assuming 2-MW turbines, the 2012 U.S. average (AWEA, 2013), and 5.5 GW of annual capacity growth.

[2] Disamenities and amenities are defined respectively as disadvantages (e.g., a nearby noxious industrial site) and advantages (e.g., a nearby park) of a location.

least squares (OLS) model, which is standard for this type of disamenity research (see, e.g., discussion in Jackson, 2003; Sirmans et al., 2005), and (2) a spatial-process model, which accounts for spatial dependence. Each type of model is used to construct a difference-in-difference (DD) specification—which simultaneously controls for preexisting amenities or disamenities in areas where turbines were sited and changes in the community after the wind facilities' construction was announced—to estimate effects near wind facilities after the turbines were announced and, later, after the turbines were constructed.[3]

The remainder of the report is structured as follows. Section 2 reviews the current literature. Section 3 details our methodology. Section 4 describes the study data. Section 5 presents the results, and Section 6 provides a discussion and concluding remarks.

2. Previous Literature

Although the topic is relatively new, the peer-reviewed literature investigating impacts to home values near wind facilities is growing. To date, results largely have coalesced around a common set of non-significant findings generated from home sales after the turbines became operational. Previous Lawrence Berkeley National Laboratory (LBNL) work in this area (Hoen et al., 2009, 2011) found no statistical evidence of adverse property-value effects due to views of and proximity to wind turbines after the turbines were constructed (i.e., post-construction or PC). Other peer-reviewed and/or academic studies also found no evidence of PC effects despite using a variety of techniques and residential transaction datasets. These include homes surrounding wind facilities in Cornwall, United Kingdom (Sims and Dent, 2007; Sims et al., 2008); multiple wind facilities in McLean County, Illinois (Hinman, 2010); near the Maple Ridge Wind Facility in New York (Heintzelman and Tuttle, 2011); and, near multiple facilities in Lee County, Illinois (Carter, 2011). Analogously, a 2012 Canadian case found a lack of evidence near a wind facility in Ontario to warrant the lowering of surrounding assessments (Kenney v MPAC, 2012). In contrast, one recent study did find impacts to land prices near a facility in North Rhine-Westphalia, Germany (Sunak and Madlener, 2012). Taken together, these results imply that the

[3] Throughout this report, the terms "announced/announcement" and "constructed/construction" represent the dates on which the proposed wind facility (or facilities) entered the public domain and the dates on which facility construction began, respectively. Home transactions can either be pre-announcement (PA), post-announcement/pre-construction (PAPC), or post-construction (PC).

PC effects of wind turbines on surrounding home values, if they exist, are often too small for detection or sporadic (i.e., a small percentage overall), or appearing in some communities for some types of properties but not others.

In the post-announcement, pre-construction period (i.e., PAPC), however, recent analysis has found more evidence of potential property value effects: by theorizing the possible existence of, but not finding, an effect (Laposa and Mueller, 2010; Sunak and Madlener, 2012); potentially finding an effect (Heintzelman and Tuttle, 2011)[4]; and, consistently finding what the author terms an "anticipation stigma" effect (Hinman, 2010). The studies that found PAPC property-value effects appear to align with earlier studies that suggested lower community support for proposed wind facilities before construction—potentially indicating a risk-averse (i.e., fear of the unknown) stance by community members—but increased support after facilities began operation (Gipe, 1995; Palmer, 1997; Devine-Wright, 2005; Wolsink, 2007; Bond, 2008, 2010). Similarly, researchers have found that survey respondents who live closer to turbines support the turbines more than respondents who live farther away (Braunholtz and MORI Scotland, 2003; Baxter et al., 2013), which could also indicate more risk-adverse / fear of the unknown effects (these among those who live farther away). Analogously, a recent case in Canada, although dismissed, highlighted the fears that nearby residents have for a planned facility (Wiggins v. WPD Canada Corporation, 2013)

Some studies have examined property-value conditions existing before wind facilities were announced (i.e., pre-announcement or PA). This is important for exploring correlations between wind facility siting and pre-existing home values from an environmental justice perspective and also for measuring PAPC and PC effects more accurately. Hoen et al. (2009, 2011) and Sims and Dent (2007) found evidence of depressed values for homes that sold before a wind facility's announcement and were located near the facility's eventual location, but they did not adjust their PC estimates for this finding. Hinman (2010) went further, finding value reductions of 12%–20% for homes near turbines in Illinois, which sold prior to the facilities' announcements; then using these findings to deflate their PC home-value-effect estimates.

[4] Heintzelman and Tuttle do not appear convinced that the effect they found is related to the PAPC period, yet the two counties in which they found an effect (Clinton and Franklin Counties, NY) had transaction data produced almost entirely in the PAPC period.

Some research has linked wind-related property-value effects with the effects of better-studied disamenities (Hoen et al., 2009). The broader disamenity literature (e.g., Boyle and Kiel, 2001; Jackson, 2001; Simons and Saginor, 2006) suggests that, although property-value effects might occur near wind facilities as they have near other disamenities, those effects (if they do exist) are likely to be relatively small, are unlikely to persist some distance from a facility, and might fade over time as home buyers who are more accepting of the condition move into the area (Tiebout, 1956).

For example, a review of the literature investigating effects near high-voltage transmission lines (a largely visual disturbance, as turbines may be for many surrounding homes) found the following: property-value reductions of 0%–15%; effects that fade with distance, often only affecting properties crossed by or immediately adjacent to a line or tower; effects that can increase property values when the right-of-way is considered an amenity; and effects that fade with time as the condition becomes more accepted (Kroll and Priestley, 1992). While potentially much more objectionable to residential communities than turbines, a review of the literature on landfills (which present odor, traffic, and groundwater-contamination issues) indicates effects that vary by landfill size (Ready, 2010). Large-volume operations (accepting more than 500 tons per day) reduce adjacent property values by 13.7% on average, fading to 5.9% one mile from the landfill. Lower-volume operations reduce adjacent property values by 2.7% on average, fading to 1.3% one mile away, with 20%–26% of lower-volume landfills not having any statistically significant impact. A study of 1,600 toxic industrial plant openings found adverse impacts of 1.5% within a half mile, which disappeared if the plants closed (Currie et al., 2012). Finally, a review of the literature on road noise (which might be analogous to turbine noise) shows property-value reductions of 0% –11% (median 4%) for houses adjacent to a busy road that experience a 10-dBA noise increase, compared with houses on a quiet street (Bateman et al., 2001).

It is not clear where wind turbines might fit into these ranges of impacts, but it seems unlikely that they would be considered as severe a disamenity as a large-volume landfill, which present odor, traffic, and groundwater-contamination issues. Low-volume landfills, with an effect near 3%, might be a better comparison, because they have an industrial (i.e., non-natural) quality, similar to turbines, but are less likely to have clear health effects. If sound is the primary

concern, a 4% effect (corresponding to road noise) could be applied to turbines, which might correspond to a 10-dBA increase for houses within a half mile of a turbine (see e.g., Hubbard and Shepherd, 1991). Finally, as with transmission lines, if houses are in sight but not within sound distance of turbines, there may be no property-value effects unless those homes are immediately adjacent to the turbines. In summary, assuming these potentially analogous disamenity effects can be entirely transferred, turbine impacts might be 0%–14%, but more likely might coalesce closer to 3%–4%.

Of course, wind turbines have certain positive qualities that landfills, transmission lines, and roads do not always have, such as mitigating greenhouse gas emissions. no air or water pollution, no use of water during the generation of energy, and no generation of solid or hazardous waste that requires permanent storage/disposal (IPCC, 2011). Moreover, wind facilities can, and often do, provide economic benefits to local communities (Lantz and Tegen, 2009; Slattery et al., 2011; Brown et al., 2012; Loomis et al., 2012), which might not be the case for all other disamenities. Similarly, wind facilities can have direct positive effects on local government budgets through property tax or other similar payments (Loomis and Aldeman, 2011), which might, for example, improve school quality and thus increase nearby home values (e.g., Haurin and Brasington, 1996; Kane et al., 2006). These potential positive qualities might mitigate potential negative wind effects somewhat or even entirely. Therefore for the purposes of this research we will assume 3-4% is a maximum possible effect.

The potentially small average property-value effect of wind turbines, possibly reduced further by wind's positive traits, might help explain why effects have not been discovered consistently in previous research. To discover effects with small margins of error, large amounts of data are needed. However, previous datasets of homes very near turbines have been small. Hoen et al. (2009, 2011) used 125 PC transactions within a mile of the turbines, while others used far fewer PC transactions within a mile: Heintzelman and Tuttle (2012) ($n \sim 35$); Hinman (2010) ($n \sim 11$), Carter (2011) ($n \sim 41$), and Sunak and Madlener (2012) ($n \sim 51$). Although these numbers of observations are adequate to examine large impacts (e.g., over 10%), they are less likely to reveal small effects with any reasonable degree of statistical significance. Using results from Hoen et al. (2009) and the confidence intervals for the various fixed-effect variables in that study, estimates for the numbers of transactions needed to find effects of various sizes were obtained.

Approximately 50 cases are needed to find an effect of 10% and larger, 100 cases for 7.5%, 200 cases for 5%, 350 cases for 4%, 700 cases for 3%, and approximately 1,000 cases for a 2.5% effect.[5] Therefore, in order to detect an effect in the range of 3%–4%, a dataset of approximately 350–700 cases within a mile of the turbines will be required to detect it statistically, a number that to-date has not been amassed by any of the previous studies.

As discussed above, in addition to being relatively small on average, impacts are likely to decay with distance. As such, an appropriate empirical approach must be able to reveal spatially diminishing effects. Some researchers have used continuous variables to capture these effects, such as linear distance (Hoen et al., 2009; Sims et al., 2008) and inverse distance (Heintzelman and Tuttle, 2012; Sunak and Madlener, 2012), but doing so forces the model to estimate effects at the mean distance. In some cases, those means can be far from the area of expected impact. For example, Heintzelman and Tuttle (2012) estimated an inverse distance effect using a mean distance of more than 10 miles from the turbines, while Sunak and Madlener (2012) used a mean distance of approximately 1.9 miles. Using this approach weakens the ability of the model to quantify real effects near the turbines, where they are likely to be stronger. More importantly, this method encourages researchers to extrapolate their findings to the ends of the distance curve, near the turbines, despite having few data at those distances to support these extrapolations. This was the case for Heintzelman and Tuttle (2012), who had fewer than 10 cases within a half mile in the two counties where effects were found and only a handful that sold in those counties after the turbines were built, yet they extrapolated their findings to a quarter mile and even a tenth of a mile, where they had very few (if any) cases. Similarly, Sunak and Madlener (2012) had only six PC sales within a half mile and 51 within 1 mile, yet they extrapolated their findings to these distance bands.

One way to avoid using a single continuous function to estimate effects at all distances is to use a spline model, which breaks the distances into continuous groups (Hoen et al., 2011), but this method still imposes structure on the data by forcing the ends of each spline to tie together. A second and more transparent method is to use fixed-effect variables for discrete distances, which imposes little structure on the data (Hoen et al., 2009; Hinman, 2010; Carter, 2011; Hoen et al.,

[5] This analysis is available upon request from the authors.

2011). Although this latter method has been used in a number of studies, because of a paucity of data, the resulting models are often ineffective at detecting what might be relatively small effects very close to the turbines. As such, when using this method (or any other, in fact) it is important that the underlying dataset is large enough to estimate the anticipated magnitude of the effect sizes.

Finally, one rarely investigated aspect of potential wind-turbine effects is the possibly idiosyncratic nature of spatially averaged transaction data used in the hedonic analyses. Sunak and Madlener (2012) used a geographically weighted regression (GWR), which estimates different regressions for small clusters of data and then allows the investigation of the distribution of effects across all of the clusters. Although GWR can be effective for understanding the range of impacts across the study area, it is not as effective for determining an average effect or for testing the statistical significance of the range of estimates. Results from studies that use GWR methods are also sometimes counter-intuitive.[6] As is discussed in more detail in the methodology section, a potentially better approach is to estimate a spatial-process model that is flexible enough to simultaneously control for spatial heterogeneity and spatial dependence, while also estimating an average effect across fixed discrete effects.

In summary, building on the existing literature, further research is needed on property-value effects in particularly close proximity to wind turbines. Specifically, research is needed that uses a large set of data near the turbines, accounts for home values before the announcement of the facility (as well as after announcement but before construction), accounts for potential spatial dependence in unobserved factors effecting home values, and uses a fixed-effect distance model that is able to accurately estimate effects near turbines.

3. Methodology

The present study seeks to respond to the identified research needs noted above, with this section describing our methodological framework for estimating the effects of wind turbines on the value of nearby homes in the United States.

[6] For example, Sunak and Madlener (2012) find larger effects related to the turbines in a city that is farther from the turbines than they find in a town which is closer. Additionally, they find stronger effects in the center of a third town than they do on the outskirts of that town, which do not seem related to the location of the turbines.

3.1. Basic Approach and Models

Our methods are designed to help answer the following questions:

1. Did homes that sold prior to the wind facilities' announcement (PA)—and located within a short distance (e.g., within a half mile) from where the turbines were eventually located—sell at lower prices than homes located farther away?
2. Did homes that sold after the wind facilities' announcement but before construction (PAPC)—and located within a short distance (e.g., within a half mile)—sell at lower prices than homes located farther away?
3. Did homes that sold after the wind facilities' construction (PC)—and located within a short distance (e.g., within a half mile)—sell at lower prices than homes located farther away?
4. For question 3 above, if no statistically identifiable effects are found, what is the likely maximum effect possible given the margins of error around the estimates?

To answer these questions, the hedonic pricing model (Rosen, 1974; Freeman, 1979) is used in this paper, as it has been in other disamenity research (Boyle and Kiel, 2001; Jackson, 2001; Simons and Saginor, 2006). The value of this approach is that is allows one to disentangle and control for the potentially competing influences of home, site, neighborhood, and market characteristics on property values, and to uniquely determine how home values near announced or operating facilities are affected.[7] To test for these effects, two pairs of "base" models are estimated, which are then coupled with a set of "robustness" models to test and bound the estimated effects. One pair is estimated using a standard OLS model, and the other is estimated using a spatial-process model. The models in each pair are different in that one focuses on all homes within 1 mile of an existing turbine (*one-mile* models), which allows the maximum number of data for the fixed effect to be used, while the other focuses on homes within a half mile (*half-mile* models), where effects are more likely to appear but fewer data are available. We assume that, if effects exist near turbines, they are larger for the *half-mile* models than the *one-mile* models.

[7] See Jackson (2003) for a further discussion of the Hedonic Pricing Model and other analysis methods.

As is common in the literature (Malpezzi, 2003; Sirmans et al., 2005), a semi-log functional form of the hedonic pricing model is used for all models, where the dependent variable is the natural log of sales price. The OLS *half-mile* model form is as follows:

$$\ln(SP_i) = \alpha + \sum_a \beta_1(T_i \bullet S_i) + \beta_2(W_i) + \sum_b \beta_3(X_i \bullet C_i) + \beta_4(D_i \bullet P_i) + \varepsilon_i \quad (1)$$

where

SP_i represents the sale price for transaction *i*,

α is the constant (intercept) across the full sample,

T_i is a vector of time-period dummy variables (e.g., sale year and if the sale occurred in winter) in which transaction *i* occurred,

S_i is the state in which transaction *i* occurred,

W_i is the census tract in which transaction *i* occurred,

X_i is a vector of home, site, and neighborhood characteristics for transaction *i* (e.g., square feet, age, acres, bathrooms, condition, percent of block group vacant and owned, median age of block group),[8]

C_i is the county in which transaction *i* occurred,

D_i is a vector of four fixed-effect variables indicating the distance (to the nearest turbine) bin (i.e., group) in which transaction *i* is located (e.g., within a half mile, between a half and 1 mile, between 1 and 3 miles, and between 3 and 10 miles),

P_i is a vector of three fixed-effect variables indicating the wind project development period in which transaction *i* occurred (e.g., PA, PAPC, PC),

$B_{1\text{-}3}$ is a vector of estimates for the controlling variables,

B_4 is a vector of 12 parameter estimates of the distance-development period interacted variables of interest,

ε_i is a random disturbance term for transaction *i*.

This pooled construction uses all property transactions in the entire dataset. In so doing, it takes advantage of the large dataset in order to estimate an average set of turbine-related effects across all study areas, while simultaneously allowing for the estimation of controlling characteristics at

[8] A "block group" is a US Census Bureau geographic delineation that contains a population between 600 to 3000 persons.

the local level, where they are likely to vary substantially across the study areas.[9] Specifically, the interaction of county-level fixed effects (C_i) with the vector of home, site, and neighborhood characteristics (X_i) allows different slopes for each of these independent variables to be estimated for each county. Similarly, interacting the state fixed-effect variables (S_i) with the sale year and sale winter fixed effects variables (T_i) (i.e., if the sale occurred in either Q1 or Q4) allows the estimation of the respective inflation/deflation and seasonal adjustments for each state in the dataset.[10] Finally, to control for the potentially unique collection of neighborhood characteristics that exist at the micro-level, census tract fixed effects are estimated.[11] Because a pooled model is used that relies upon the full dataset, smaller effect sizes for wind turbines will be detectable. At the same time, however, this approach does not allow one to distinguish possible wind turbine effects that may be larger in some communities than in others.

As discussed earlier, effects might predate the announcement of the wind facility and thus must be controlled for. Additionally, the area surrounding the wind facility might have changed over time simultaneously with the arrival of the turbines, which could affect home values. For example, if a nearby factory closed at the same time a wind facility was constructed, the influence of that factor on all homes in the general area would ideally be controlled for when estimating wind turbine effect sizes.

To control for both of these issues simultaneously, we use a difference-in-difference (*DD)* specification (see e.g., Hinman, 2010; Zabel and Guignet, 2012) derived from the interaction of

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[9] The dataset does not include "participating" landowners, those that have turbines situated on their land, but does include "neighboring" landowners, those adjacent to or nearby the turbines. One reviewer notes that the estimated average effects also include any effects from payments "neighboring" landowners might receive that might transfer with the home. Based on previous conversations with developers (see Hoen et al, 2009), we expect that the frequency of these arrangements is low, as is the right to transfer the payments to the new homeowner. Nonetheless, our results should be interpreted as "net" of any influence whatever "neighboring" landowner arrangements might have.

[10] Unlike the vector of home, site, and neighborhood characteristics, sale price inflation/deflation and seasonal changes were not expected tovary substantially across various counties in the same states in our sample and therefore the interaction was made at the state level. This assumption was tested as part of the robustness tests though, where they are interacted at the county level and found to not affect the results.

[11] In part because of the rural nature of many of the study areas included in the research sample, these census tracts are large enough to contain sales that are located close to the turbines as well as those farther away, thereby ensuring that they do not unduly absorb effects that might be related to the turbines. Moreover each tract contains sales from throughout the study periods, both before and after the wind facilities' announcement and construction, further ensuring they are not biasing the variables of interest.

the spatial (D_i) and temporal (P_i) terms. These terms produce a vector of 11 parameter estimates (β_4) as shown in Table 1 for the *half-mile* models and in Table 2 for the *one-mile* models. The omitted (or reference) group in both models is the set of homes that sold prior to the wind facilities' announcement and which were located more than 3 miles away from where the turbines were eventually located (A3). It is assumed that this reference category is likely not affected by the imminent arrival of the turbines, although this assumption is tested in the robustness tests.

Using the *half-mile* models, to test whether the homes located near the turbines that sold in the PA period were uniquely affected (*research question 1*), we examine A0, from which the null hypothesis is A0=0. To test if the homes located near the turbines that sold in the PAPC period were uniquely affected (*research question 2*), we first determine the difference in their values as compared to those farther away (B0-B3), while also accounting for any pre-announcement (i.e., pre-existing) difference (A0-A3) and any change in the local market over the development period (B3-A3). Because all covariates are determined in relation to the omitted category (A3), the null hypothesis collapses B0-A0-B3=0. Finally, in order to determine if homes near the turbines that sold in the PC period were uniquely affected (*research question 3*), we test if C0-A0-C3=0. Each of these *DD* tests are estimated using a linear combination of variables that produces the "net effect" and a measure of the standard error and corresponding confidence intervals of the effect, which enables the estimation of the maximum (and minimum) likely impacts for each research question. We use 90% confidence intervals both to determine significance and to estimate maximum likely effects (*research question 4*).

Following the same logic as above, the corresponding hypothesis tests for the *one-mile* models are as follows: *PA*, A1=0; *PAPC*, B1-A1-B3=0; and, *PC*, C1-A1-C3=0.

Table 1: Interactions between Wind Facility Development Periods and Distances – ½ Mile

Wind Facility Development Periods	Distances to Nearest Turbine			
	Within 1/2 Mile	Between 1/2 and 1 Mile	Between 1 and 3 Miles	Outside of 3 Miles
Prior to Announcement	A0	A1	A2	A3 (Omitted)
After Announcement but Prior to Construction	B0	B1	B2	B3
Post Construction	C0	C1	C2	C3

Table 2: Interactions between Wind Facility Development Periods and Distances - 1 Mile

Wind Facility Development Periods	Distances to Nearest Turbine		
	Within 1 Mile	Between 1 and 3 Miles	Outside of 3 Miles
Prior to Announcement	A1	A2	A3 (Omitted)
After Announcement but Prior to Construction	B1	B2	B3
Post Construction	C1	C2	C3

3.2. Spatial Dependence

As discussed briefly above, a common feature of the data used in hedonic models is the spatially dense nature of the real estate transactions. While this spatial density can provide unique insights into local real estate markets, one concern that is often raised is the impact of potentially omitted variables given that this is impossible to measure all of the local characteristics that affect housing prices. As a result, spatial dependence in a hedonic model is likely because houses located closer to each other typically have similar unobservable attributes. Any correlation between these unobserved factors and the explanatory variables used in the model (e.g., distance to turbines) is a source of omitted-variable bias in the OLS models. A common approach used in

the hedonic literature to correct this potential bias is to include local fixed effects (Hoen et al., 2009, 2011; Zabel and Guignet, 2012), which is our approach as described in formula (1).

In addition to including local fixed effects, spatial econometric methods can be used to help further mitigate the potential impact of spatially omitted variables by modeling spatial dependence directly. When spatial dependence is present and appropriately modeled, more accurate (i.e., less biased) estimates of the factors influencing housing values can be obtained. These methods have been used in a number of previous hedonic price studies; examples include the price impacts of wildfire risk (Donovan et al., 2007), residential community associations (Rogers, 2006), air quality (Anselin and Lozano-Gracia, 2009), and spatial fragmentation of land use (Kuethe, 2012). To this point, however, these methods have not been applied to studies of the impact of wind turbines on property values.

Moran's I is the standard statistic used to test for spatial dependence in OLS residuals of the hedonic equation. If the Moran's I is statistically significant (as it is in our models – see Section 5.1.2), the assumption of spatial independence is rejected. To account for this, in spatial-process models, spatial dependence is routinely modeled as an additional covariate in the form of a spatially lagged dependent variable *Wy*, or in the error structure $\mu = \lambda W\mu + \varepsilon$, where ε is an identically and independently distributed disturbance term (Anselin, 1988). Neighboring criterion determines the structure of the spatial weights matrix *W*, which is frequently based on contiguity, distance criterion, or *k*-nearest neighbors (Anselin, 2002). The weights in the spatial-weights matrix are typically row standardized so that the elements of each row sum to one.

The spatial-process model, known as the SARAR model (Kelejian and Prucha, 1998)[12], allows for both forms of spatial dependence, both as an autoregressive process in the lag-dependent and in the error structure, as shown by:

$$\begin{aligned} y &= \rho Wy + X\beta + \mu, \\ \mu &= \lambda W\mu + \varepsilon. \end{aligned} \tag{2}$$

[12] SARAR refers to a "spatial-autoregressive model with spatial autoregressive residuals".

Equation (2) is often estimated by a multi-step procedure using generalized moments and instrumental variables (Arraiz et al., 2009), which is our approach. The model allows for the innovation term ε in the disturbance process to be heteroskedastic of an unknown form (Kelejian and Prucha, 2010). If either λ or ρ are not significant, the model reduces to the respective spatial lag or spatial error model (SEM). In our case, as is discussed later, the spatial process model reduces to the SEM, therefore both *half-mile* and *one-mile* SEMs are estimated, and, as with the OLS models discussed above, a similar set of *DD* "net effects" are estimated for the PA, PAPC, and PC periods. One requirement of the spatial model is that the x/y coordinates be unique across the dataset. However, the full set of data (as described below) contains, in some cases, multiple sales for the same property, which consequently would have non-unique x/y coordinates.[13] Therefore, for the spatial models, only the most recent sale is used. An OLS model using this limited dataset is also estimated as a robustness test.

In total, four "base" models are estimated: an OLS *one-mile* model, a SEM *one-mile* model, an OLS *half-mile* model, and a SEM *half-mile* model. In addition, a series of robustness models are estimated as described next.

3.3. Robustness Tests

To test the stability of and potentially bound the results from the four base models, a series of robustness tests are conducted that explore: the effect that outliers and influential cases have on the results; a micro-inflation/deflation adjustment by interacting the sale-year fixed effects with the county fixed effects rather than state fixed effects; the use of only the most recent sale of homes in the dataset to compare results to the SEM models that use the same dataset; the application of a more conservative reference category by using transactions between 5 and 10 miles (as opposed to between 3 and 10 miles) as the reference; and a more conservative

[13] The most recent sale weights the transactions to those occurring after announcement and construction, that are more recent in time. One reviewer wondered if the frequency of sales was affected near the turbines, which is also outside the scope of the study, though this "sales volume" was investigated in Hoen et al. (2009), where no evidence of such an effect was discovered. Another correctly noted that the most recent assessment is less accurate for older sales, because it might overestimate some characteristics of the home (e.g., sfla, baths) that might have changed (i.e., increased) over time. This would tend to bias those characteristics' coefficients downward. Regardless, it is assumed that this occurrence is not correlated with proximity to turbines and therefore would not bias the variables of interest.

reference category by using transactions more than 2 years PA (as opposed to simply PA) as the reference category. Each of these tests is discussed in detail below.

3.3.1. Outliers and Influential Cases

Most datasets contain a subset of observations with particularly high or low values for the dependent variables, which might bias estimates in unpredictable ways. In our robustness test, we assume that observations with sales prices above or below the 99% and 1% percentile are potentially problematic outliers. Similarly, individual sales transactions and the values of the corresponding independent variables might exhibit undue influence on the regression coefficients. In our analysis, we therefore estimate a set of Cook's Distance statistics (Cook, 1977; Cook and Weisberg, 1982) on the base OLS *half-mile* model and assume any cases with an absolute value of this statistic greater than one to be potentially problematic influential cases. To examine the influence of these cases on our results, we estimate a model with both the outlying sales prices and Cook's influential cases removed.

3.3.2. Interacting Sale Year at the County Level

It is conceivable that housing inflation and deflation varied dramatically in different parts of the same state. In the base models, we interact sale year with the state to account for inflation and deflation of sales prices, but a potentially more-accurate adjustment might be warranted. To explore this, a model with the interaction of sale year and county, instead of state, is estimated.

3.3.3. Using Only the Most Recent Sales

The dataset for the base OLS models includes not only the most recent sale of particular homes, but also, if available, the sale prior to that. Some of these earlier sales occurred many years prior to the most recent sale. The home and site characteristics (square feet, acres, condition, etc.) used in the models are populated via assessment data for the home. For some of these data, only the most recent assessment information is available (rather than the assessment from the time of sale), and therefore older sales might be more prone to error as their characteristics might have

changed since the sale.[14] Additionally, the SEMs require that all x/y coordinates entered into the model are unique; therefore, for those models only the most recent sale is used. Excluding older sales therefore potentially reduces measurement error, and also enables a more-direct comparison of effects between the base OLS model and SEM results.

3.3.4. Using Homes between 5 and 10 Miles as Reference Category

The base models use the collection of homes between 3 and 10 miles from the wind facility (that sold before the announcement of the facility) as the reference category in which wind facility effects are not expected. However, it is conceivable that wind turbine effects extend farther than 3 miles. If homes outside of 3 miles are affected by the presence of the turbines, then effects estimated for the target group (e.g., those inside of 1 mile) will be biased downward (i.e., smaller) in the base models. To test this possibility and ensure that the results are not biased, the group of homes located between 5 and 10 miles is used as a reference category as a robustness test.

3.3.5. Using Transactions Occurring More than 2 Years before Announcement as Reference Category

The base models use the collection of homes that sold before the wind facilities were announced (and were between 3 and 10 miles from the facilities) as the reference category, but, as discussed in Hoen et al. (2009, 2011), the announcement date of a facility, when news about a facility enters the public domain, might be after that project was known in private. For example, wind facility developers may begin talking to landowners some time before a facility is announced, and these landowners could share that news with neighbors. In addition, the developer might erect an anemometer to collect wind-speed data well before the facility is formally "announced," which might provide concrete evidence that a facility may soon to be announced. In either case, this news might enter the local real estate market and affect home prices before the formal facility announcement date. To explore this possibility, and to ensure that the reference category

[14] As discussed in more detail in the Section 4, approximately 60% of all the data obtained for this study (that obtained from CoreLogic) used the most recent assessment to populate the home and site characteristics for all transactions of a given property.

is unbiased, a model is estimated that uses transactions occurring more than 2 years before the wind facilities were announced (and between 3 and 10 miles) as the reference category.

Combined, this diverse set of robustness tests allows many assumptions used for the base models to be tested, potentially allowing greater confidence in the final results.

4. Data

The data used for the analysis are comprised of four types: wind turbine location data, real estate transaction data, home and site characteristic data, and census data. From those, two additional sets of data are calculated: distance to turbine and wind facility development period. Each data type is discussed below. Where appropriate, variable names are shown in *italics*.

4.1. Wind Turbine Locations

Location data (i.e., x/y coordinates) for installed wind turbines were obtained via an iterative process starting with Federal Aviation Administration obstacle data, which were then linked to specific wind facilities by Ventyx[15] and matched with facility-level data maintained by LBNL. Ultimately, data were collected on the location of almost all wind turbines installed in the U.S. through 2011 (n ~ 40,000), with information about each facility's announcement, construction, and operation dates as well as turbine nameplate capacity, hub height, rotor diameter, and facility size.

4.2. Real Estate Transactions

Real estate transaction data were collected through two sources, each of which supplied the home's sale price (*sp*), sale date (*sd*), x/y coordinates, and address including zip code. From those, the following variables were calculated: natural log of sale price (*lsp*), sale year (*sy*), if the sale occurred in winter (*swinter*) (i.e., in Q1 or Q4).

The first source of real estate transaction data was CoreLogic's extensive dataset of U.S. residential real estate information.[16] Using the x/y coordinates of wind turbines, CoreLogic

[15] See the EV Energy Map, which is part of the Velocity Suite of products at www.ventyx.com.
[16] See www.corelogic.com.

selected all arms-length single-family residential transactions between 1996 and 2011 within 10 miles of a turbine in any U.S. counties where they maintained data (not including New York – see below) on parcels smaller than 15 acres.[17] The full set of counties for which data were collected were then winnowed to 26 by requiring at least 250 transactions in each county, to ensure a reasonably robust estimation of the controlling characteristics (which, as discussed above, are interacted with county-level fixed effects), and by requiring at least one PC transaction within a half mile of a turbine in each county (because this study's focus is on homes that are located in close proximity to turbines).

The second source of data was the New York Office of Real Property Tax Service (NYORPTS),[18] which supplied a set of arms-length single-family residential transactions between 2001 and 2012 within 10 miles of existing turbines in any New York county in which wind development had occurred prior to 2012. As before, only parcels smaller than 15 acres were included, as were a minimum of 250 transactions and at least one PC transaction within a half mile of a turbine for each New York county. Both CoreLogic and NYORPTS provided the most recent home sale and, if available, the prior sale.

4.3. Home and Site Characteristics

A set of home and site characteristic data was also collected from both data suppliers: 1000s of square feet of living area (*sfla1000*), number of acres of the parcel (*acres*), year the home was built (or last renovated, whichever is more recent) (*yrbuilt*), and the number of full and half bathrooms (*baths*).[19] Additional variables were calculated from the other variables as well: log of 1,000s of square feet (*lsfla1000*),[20] the number of acres less than 1 (*lt1acre)*,[21] age at the time of sale (*age*), and age squared (*agesqr*).[22]

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[17] The 15 acre screen was used because of a desire to exclude from the sample any transaction of property that might be hosting a wind turbine, and therefore directly benefitting from the turbine's presence (which might then increase property values). To help ensure that the screen was effective, all parcels within a mile of a turbine were also visually inspected using satellite and ortho imagery via a geographic information system.

[18] See www.orps.state.ny.us

[19] *Baths* was calculated in the following manner: full bathrooms + (half bathrooms x 0.5). Some counties did not have *baths* data available, so for them *baths* was not used as an independent variable.

[20] The distribution of *sfla1000* is skewed, which could bias OLS estimates, thus *lsfla1000* is used instead, which is more normally distributed. Regression results, though, were robust when *sfla1000* was used instead.

Regardless of when the sale occurred, CoreLogic supplied the related home and site characteristics as of the most recent assessment, while NYORPTS supplied the assessment data as of the year of sale.[23]

4.4. Census Information

Each of the homes in the data was matched (based on the x/y coordinates) to the underlying census block group and tract via ArcGIS. Using the year 2000 block group census data, each transaction was appended with neighborhood characteristics including the median age of the residents (*medage*), the total number of housing units (*units*), the number vacant (*vacant*) homes, and the number of owned (*owned*) homes. From these, the percentages of the total number of housing units in the block group that were vacant and owned were calculated, i.e., *pctvacant* and *pctowned*.

4.5. Distances to Turbine

Using the x/y coordinates of both the homes and the turbines, a Euclidian distance (in miles) was calculated for each home to the nearest wind turbine (*tdis*), regardless of when the sale occurred (e.g., even if a transaction occurred prior to the wind facility's installation).[24] These were then broken into four mutually exclusive distance bins (i.e., groups) for the base *half-mile* models: inside a half mile, between a half and 1 mile, between 1 and 3 miles, and between 3 and 10 miles. They were broken into three mutually exclusive bins for the base *one-mile* models: inside 1 mile, between 1 and 3 miles, and between 3 and 10 miles.

4.6. Wind Facility Development Periods

After identifying the nearest wind turbine for each home, a match could be made to Ventyx' dataset of facility-development announcement and construction dates. These facility-development dates in combination with the dates of each sale of the homes determined in which

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[21] This variable allows the separate estimations of the 1st acre and any additional acres over the 1st.

[22] *Age* and *agesqr* together account for the fact that, as homes age, their values usually decrease, but further increases in age might bestow countervailing positive "antique" effects.

[23] See footnote 13.

[24] Before the distances were calculated, each home inside of 1 mile was visually inspected using satellite and ortho imagery, with x/y coordinates corrected, if necessary, so that those coordinates were on the roof of the home.

of the three facility-development periods (*fdp*) the transaction occurred: *pre-announcement* (PA), *post-announcement-pre-construction* (PAPC), or *post-construction* (PC).

4.7. Data Summary

After cleaning to remove missing or erroneous data, a final dataset of 51,276 transactions was prepared for analysis.[25] As shown in the map of the study area (Figure 1), the data are arrayed across nine states and 27 counties (see Table 4), and surround 67 different wind facilities.

Table 3 contains a summary of those data. The average unadjusted sales price for the sample is $122,475. Other average house characteristics include the following: 1,600 square feet of living space; house age of 48 years[26]; land parcel size of 0.90 acres; 1.6 bathrooms; in a block group in which 74% of housing units are owned, 9% are vacant, and the median resident age is 38 years; located 4.96 miles from the nearest turbine; and sold at the tail end of the PA period.

The data are arrayed across the temporal and distance bins as would be expected, with smaller numbers of sales nearer the turbines, as shown in Table 5. Of the full set of sales, 1,198 occurred within 1 mile of a then-current or future turbine location, and 376 of these occurred post construction; 331 sales occurred within a half mile, 104 of which were post construction. Given these totals, the models should be able to discern a post construction effect larger than ~3.5% within a mile and larger than ~7.5% within a half mile (see discussion in Section 2). These effects are at the top end of the expected range of effects based on other disamenities (high-voltage power lines, roads, landfills, etc.).

[25] Cleaning involved the removal of all data that did not have certain core characteristics (sale date, sale price, *sfla*, *yrbuilt*, *acres*, *median age*, etc.) fully populated as well as the removal of any sales that had seemingly miscoded data (e.g., having a *sfla* that was greater than *acres*, having a *yrbuilt* more than 1 year after the sale, having less than one *bath*) or that did not conform to the rest of the data (e.g., had *acres* or *sfla* that were either larger or smaller, respectively, than 99% or 1% of the data). OLS models were rerun with those "nonconforming" data included with no substantive change in the results in comparison to the screened data presented in the report.

[26] Age could be as low as -1(for a new home) for homes that were sold before construction was completed.

Figure 1: Map of Transactions, States, and Counties

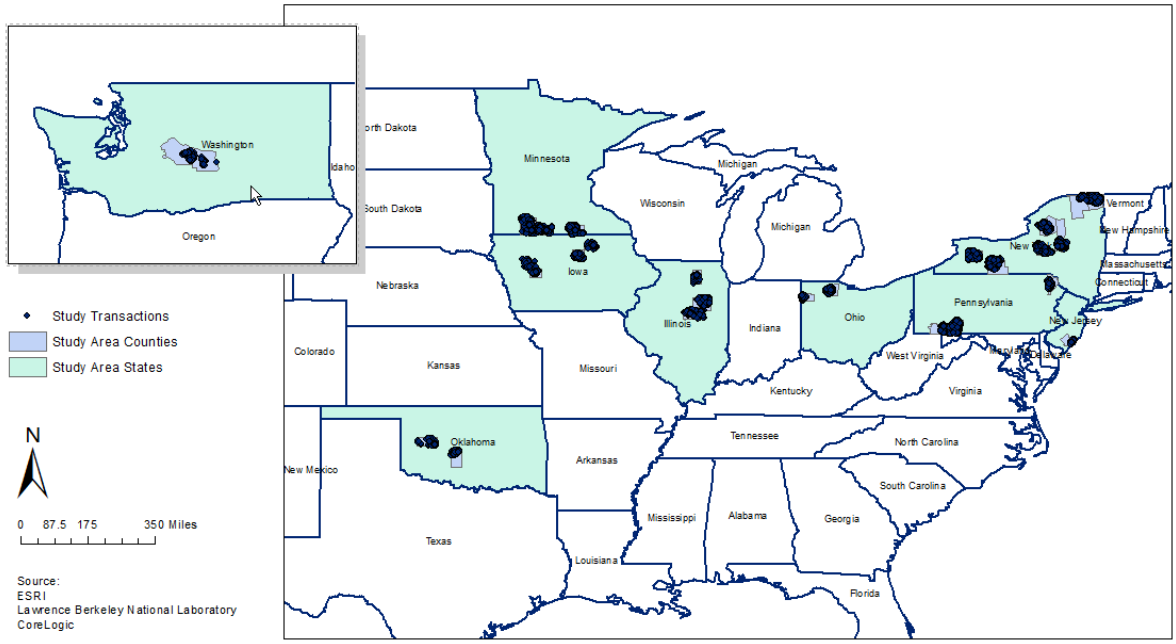


Table 3: Summary Statistics

Variable	Description	Mean	Std. Dev.	Min	Max
sp	sale price in dollars	$ 122,475	$ 80,367	$ 9,750	$ 690,000
lsp	natural log of sale price	11.52	0.65	9.19	13.44
sd	sale date	1/18/2005	1,403 days	1/1/1996	9/30/2011
sy	sale year	2005	3.84	1996	2011
sfla1000	living area in 1000s of square feet	1.60	0.57	0.60	4.50
lsfla1000	natural log of sfla1000	0.41	0.34	-0.50	1.50
acres	number of acres in parcel	0.90	1.79	0.03	14.95
acreslt1*	acres less than 1	-0.58	0.34	-0.97	0.00
age	age of home at time of sale	48	37	-1	297
agesq	age squared	3689	4925	0	88209
baths**	number of bathrooms	1.60	0.64	1.00	5.50
pctowner	fraction of house units in block group that are owned (as of 2000)	0.74	0.17	0.63	0.98
pctvacant	fraction of house units in block group that are vacant (as of 2000)	0.09	0.10	0.00	0.38
med_age	median age of residents in block group (as of 2000)	38	6	20	63
tdis	distance to nearest turbine (as of December 2011) in miles	4.96	2.19	0.09	10.00
fdp***	facility development period of nearest turbine at time of sale	1.94	0.87	1.00	3.00
Note: The number of cases for the full dataset is 51,276					
** acreslt1 is calculated as follows: acres (if less than 1) * - 1*					
*** Some counties did not have bathrooms populated; for those, these variables are entered into the regression as 0.*					
**** fdp periods are: 1, pre-announcement,; 2, post-announcement-pre-construction; and, 3, post-construction.*					

Table 4: Summary of Transactions by County

County	State	<1/2 mile	1/2-1 mile	1-3 miles	3-10 miles	Total
Carroll	IA	12	56	331	666	1,065
Floyd	IA	3	2	402	119	526
Franklin	IA	8	1	9	322	340
Sac	IA	6	77	78	485	646
DeKalb	IL	4	8	44	605	661
Livingston	IL	16	6	237	1,883	2,142
McLean	IL	18	88	380	4,359	4,845
Cottonwood	MN	3	10	126	1,012	1,151
Freeborn	MN	17	16	117	2,521	2,671
Jackson	MN	19	28	36	149	232
Martin	MN	7	25	332	2,480	2,844
Atlantic	NJ	34	96	1,532	6,211	7,873
Paulding	OH	15	58	115	309	497
Wood	OH	5	31	563	4,844	5,443
Custer	OK	45	24	1,834	349	2,252
Grady	OK	1	6	97	874	978
Fayette	PA	1	2	10	284	297
Somerset	PA	23	100	1,037	2,144	3,304
Wayne	PA	4	29	378	739	1,150
Kittitas	WA	2	6	61	349	418
Clinton	NY	4	6	49	1,419	1,478
Franklin	NY	16	41	75	149	281
Herkimer	NY	3	17	354	1,874	2,248
Lewis	NY	5	6	93	732	836
Madison	NY	5	26	239	3,053	3,323
Steuben	NY	5	52	140	1,932	2,129
Wyoming	NY	50	50	250	1,296	1,646
Total		331	867	8,919	41,159	51,276

Table 5: Frequency Crosstab of Wind Turbine Distance and Development Period Bins

	<1/2 mile	1/2-1 mile	1-3 miles	3-10 miles	total
PA	143	383	3,892	16,615	21,033
PAPC	84	212	1,845	9,995	12,136
PC	104	272	3,182	14,549	18,107
total	331	867	8,919	41,159	51,276

As shown in Table 6, the home sales occurred around wind facilities that range from a single-turbine project to projects of 150 turbines, with turbines of 290–476 feet (averaging almost 400 feet) in total height from base to tip of blade and with an average nameplate capacity of 1,637 kW. The average facility was announced in 2004 and constructed in 2007, but some were announced as early as 1998 and others were constructed as late as 2011.

Table 6: Wind Facility Summary

	mean	min	25th percentile	median	75th percentile	max
turbine rotor diameter (feet)	262	154	253	253	269	328
turbine hub height (feet)	256	197	256	262	262	328
turbine total height (feet)	388	290	387	389	397	476
turbine capacity (kW)	1637	660	1500	1500	1800	2500
facility announcement year	2004	1998	2002	2003	2005	2010
facility construction year	2007	2000	2004	2006	2010	2011
number of turbines in facility	48	1	5	35	84	150
nameplate capacity of facility (MW)	79	1.5	7.5	53	137	300

Note: The data correspond to 67 wind facilities located in the study areas. Mean values are rounded to integers

4.8. Comparison of Means

To provide additional context for the analysis discussed in the next section, we further summarize the data here using four key variables across the sets of development period (*fdp*) and distance bins (*tdis*) used in the *one-mile* models.[27] The variables are the dependent variable log of sale price *(lsp)* and three independent variables: *lsfla100*, *acres*, and *age*. These summaries are provided in Table 7; each sub-table gives the mean values of the variables across the three *fdp* bins and three *tdis* bins, and the corresponding figures plot those values.

The top set of results are focused on the log of the sales price, and show that, based purely on price and not controlling for differences in homes, homes located within 1 mile of turbines had lower sale prices than homes farther away; this is true across all of the three development periods. Moreover, the results also show that, over the three periods, the closer homes appreciated to a somewhat lesser degree than homes located farther from the turbines. As a result, focusing only on the post-construction period, these results might suggest that home prices near turbines are

[27] Summaries for the *half-mile* models reveal a similar relationship, so only the *one-mile* model summaries are shown here.

adversely impacted by the turbines. After all, the logarithmic values for the homes within a mile of the turbines (11.39) and those outside of a three miles (11.72) translate into an approximately 40% difference, in comparison to an 21% difference before the wind facilities were announced (11.16 vs. 11.35).[28] Focusing on the change in average values between the pre-announcement and post-construction periods might also suggest an adverse effect due to the turbines, because homes inside of 1 mile appreciated more slowly (11.16 to 11.39, or 25%) than those outside of 3 miles (11.35 to 11.72, or 45%). Both conclusions of adverse turbine effects, however, disregard other important differences between the homes, which vary over the periods and distances. Similarly, comparing the values of the PA inside 1 mile homes (11.16) and the PC outside of 3 miles homes (11.72), which translates into a difference of 75%, and which is the basis for comparison in the regressions discussed below, but also ignores any differences in the underlying characteristics.

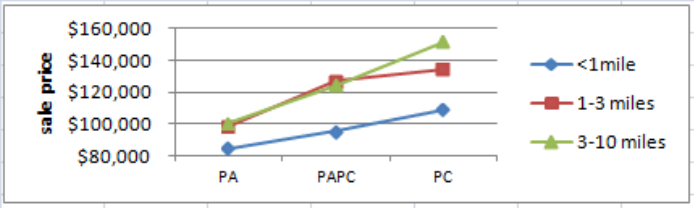
The remainder of Table 7, for example, indicates that, although the homes that sold within 1 mile are lower in value, they are also generally (in all but the PA period) smaller, on larger parcels of land, and older. These differences in home size and age across the periods and distances might explain the differences in price, while the differences in the size of the parcel, which add value, further amplifying the differences in price. Without controlling for these possible impacts, one cannot reliably estimate the impact of wind turbines on sales prices.

In summary, focusing solely on trends in home price (or price per square foot) alone, and for only the PC period, as might be done in a simpler analysis, might incorrectly suggest that wind turbines are affecting price when other aspects of the markets, and other home and sites characteristic differences, could be driving the observed price differences. This is precisely why researchers generally prefer the hedonic model approach to control for such effects, and the results from our hedonic OLS and spatial modeling detailed in the next section account for these and many other possible influencing factors.

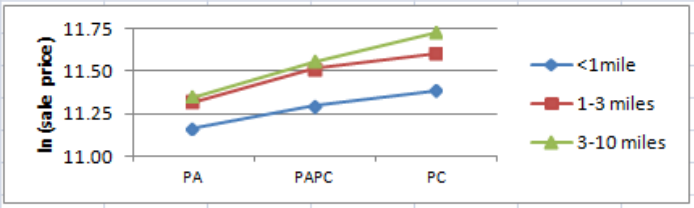
[28] Percentage differences are calculated as follows: exp(11.72-11.39)-1=0.40 and exp(11.35-11.16)-1=0.21.

Table 7: Dependent and Independent Variable Means

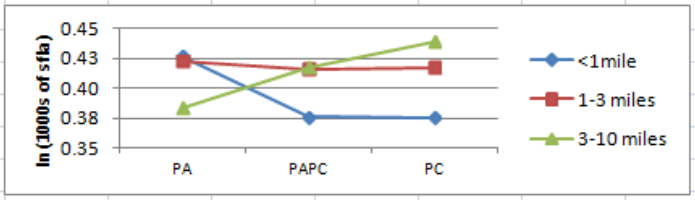
Sale Price			
	<1mile	1-3 miles	3-10 miles
PA	$ 84,830	$ 98,676	$100,485
PAPC	$ 95,223	$127,054	$124,532
PC	$109,133	$134,647	$151,559



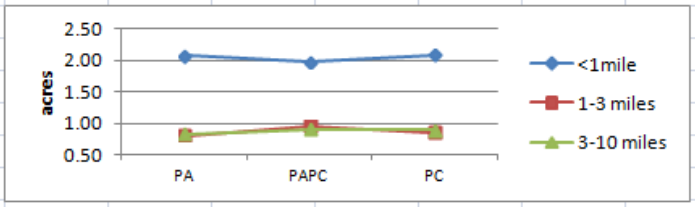
Log of Sale Price			
	<1mile	1-3 miles	3-10 miles
PA	11.16	11.32	11.35
PAPC	11.30	11.52	11.56
PC	11.39	11.61	11.72



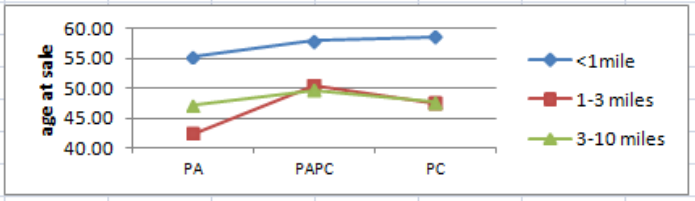
Log of Square Feet (in 1000s)			
	<1mile	1-3 miles	3-10 miles
PA	0.43	0.42	0.38
PAPC	0.38	0.42	0.42
PC	0.38	0.42	0.44



Number of Acres			
	<1mile	1-3 miles	3-10 miles
PA	2.08	0.80	0.83
PAPC	1.98	0.94	0.90
PC	2.09	0.84	0.89



Age at the Time of Sale			
	<1mile	1-3 miles	3-10 miles
PA	55.32	42.34	47.19
PAPC	58.01	50.34	49.73
PC	58.63	47.39	47.73



5. Results

This section contains analysis results and discussion for the four base models, as well as the results from the robustness models.

5.1. Estimation Results for Base Models

Estimation results for the "base" models are shown in Table 8 and Table 9.[29] In general, given the diverse nature of the data, the models perform adequately, with adjusted R^2 values ranging from 0.63 to 0.67 (bottom of Table 9).

5.1.1. Control Variables

The controlling home, site, and block group variables, which are interacted at the county level, are summarized in Table 8. Table 8 focuses on only one of the base models, the *one-mile* OLS model, but full results from all models are shown in the Appendix. [30] To concisely summarize results for all of the 27 counties, the table contains the percentage of all 27 counties for which each controlling variable has statistically significant (at or below the 10% level) coefficients for the *one-mile* OLS model. For those controlling variables that are found to be statistically significant, the table further contains mean values, standard deviations, and minimum and maximum levels.

Many of the county-interacted controlling variables (e.g., *lsfla1000, lt1acre, age, agesqr, baths,* and *swinter*) are consistently (in more than two thirds of the counties) statistically significant (with a *p*-value < 0.10) and have appropriately sized mean values. The seemingly spurious minimum and maximum values among some of the county-level controlling variables (e.g., *lt1acre* minimum of -0.069) likely arise when these variables in particular counties are highly correlated with other variables, such as square feet (*lsfla1000*), and also when sample size is limited.[31] The other variables (*acres* and the three block group level census variables: *pctvacant, pctowner,* and *med_age*) are statistically significant in 33-59% of the counties. Only one variable's mean value—the percent of housing units vacant in the block group as of the 2000 census (*pctvacant*)—was counterintuitive. In that instance, a positive coefficient was estimated, when in fact, one would expect that increasing the percent of vacant housing would lower prices;

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[29] The OLS models are estimated using the areg procedure in Stata with robust (White's corrected) standard errors (White, 1980). The spatial error models are estimated using the *gstslshet* routine in the sphet package in R, which also allows for robust standard errors to be estimated. See: http://cran.r-project.org/web/packages/sphet/sphet.pdf

[30] The controlling variables' coefficients were similar across the base models, so only the *one-mile* results are summarized here.

[31] The possible adverse effects of these collinearities were fully explored both via the removal of the variables and by examining VIF statistics. The VOI results are robust to controlling variable removal and have relatively low (< 5) VIF statistics.

this counter-intuitive effect may be due to collinearity with one or more of the other variables, or possible measurement errors.[32]

The sale year variables, which are interacted with the state, are also summarized in Table 8, with the percentages indicating the number of states in which the coefficients are statistically significant. The inclusion of these sale year variables in the regressions control for inflation and deflation across the various states over the study period. The coefficients represent a comparison to the omitted year, which is 2011. All sale year state-level coefficients are statistically significant in at least 50% of the states in all years except 2010, and they are significant in two thirds of the states in all except 3 years. The mean values of all years are appropriately signed, showing a monotonically ordered peak in values in 2007, with lower values in the prior and following years. The minimum and maximum values are similarly signed (negative) through 2003 and from 2007 through 2010 (positive), and are both positive and negative in years 2003 through 2006, indicating the differences in inflation/deflation in those years across the various states. This reinforces the appropriateness of interacting the sale years at the state level. Finally, although not shown, the model also contains 250 fixed effects for the census tract delineations, of which approximately 50% were statistically significant.

[32] The removal of this, as well as the other block group census variables, however, did not substantively influence the results of the VOI.

Table 8: Levels and Significance for County- and State-Interacted Controlling Variables[33]

Variable	% of Counties/States Having Significant (*p* -value <0.10) Coefficients	Statistics for Significant Variables			
		Mean	St Dev	Min	Max
lsfla1000	100%	0.604	0.153	0.332	0.979
acres	48%	0.025	0.035	-0.032	0.091
lt1acre	85%	0.280	0.170	-0.069	0.667
age	81%	-0.006	0.008	-0.021	0.010
agesqr	74%	-0.006	0.063	-0.113	0.108
*baths**	85%	0.156	0.088	0.083	0.366
pctvacant	48%	1.295	3.120	-2.485	9.018
pctowner	33%	0.605	0.811	-0.091	2.676
med_age	59%	-0.016	0.132	-0.508	0.066
swinter	78%	-0.034	0.012	-0.053	-0.020
sy1996	100%	-0.481	0.187	-0.820	-0.267
sy1997	100%	-0.448	0.213	-0.791	-0.242
sy1998	100%	-0.404	0.172	-0.723	-0.156
sy1999	100%	-0.359	0.169	-0.679	-0.156
sy2000	88%	-0.298	0.189	-0.565	-0.088
sy2001	88%	-0.286	0.141	-0.438	-0.080
sy2002	67%	-0.261	0.074	-0.330	-0.128
sy2003	67%	-0.218	0.069	-0.326	-0.119
sy2004	75%	-0.084	0.133	-0.208	0.087
sy2005	67%	0.082	0.148	-0.111	0.278
sy2006	67%	0.128	0.158	-0.066	0.340
sy2007	67%	0.196	0.057	0.143	0.297
sy2008	56%	0.160	0.051	0.084	0.218
sy2009	50%	0.138	0.065	0.071	0.219
sy2010	33%	0.172	0.063	0.105	0.231

** % of counties significant is reported only for counties that had the baths variable populated (17 out of 27 counties)*

5.1.2. Variables of Interest

The variables of interest, the interactions between the *fdp* and *tdis* bins, are shown in Table 9 for the four base models. The reference (i.e., omitted) case for these variables are homes that sold prior to the wind facilities' announcement (PA) and are located between 3 and 10 miles from the

[33] Controlling variable statistics are provided for only the *one-mile* OLS model but did not differ substantially for other models. All variables are interacted with counties, except for sale year (sy), which is interacted with the state.

wind turbines' eventual locations. In relation to that group of transactions, three of the eight interactions in the *one-mile* models and four of the 11 interactions in the *half-mile* models produce coefficients that are statistically significant (at the 10% level).

Across all four base models none of the PA coefficients show statistically significant differences between the reference category (outside of 3 miles) and the group of transactions within a mile for the *one-mile* models (OLS: -1.7%, *p*-value 0.48; SEM: -0.02%, *p*-value 0.94)[34] or within a half- or between one-half and one-mile for the *half-mile* models (OLS inside a half mile: 0.01%, *p*-value 0.97; between a half and 1 mile: -2.3%, *p*-value 0.38; SEM inside a half mile: 5.3%, *p*-value 0.24; between a half and 1 mile: -1.8%, *p*-value 0.60). Further, none of the coefficients are significant, and all are relatively small (which partially explains their non-significance). Given these results, we find an absence of evidence of a PA effect for homes close to the turbines (*research question 1*). These results can be contrasted with the differences in prices between within-1-mile homes and outside-of-3-miles homes as summarized in Section 4.8 when no differences in the homes, the local market, the neighborhood, etc. are accounted for. The approximately 75% difference in price (alone) in the pre-announcement period 1-mile homes, as compared to the PC 3-mile homes, discussed in Section 4.8, is largely explained by differences in the controlling characteristics, which is why the pre-announcement distance coefficients shown here are not statistically significant.

Turning to the PAPC and PC periods, the results also indicate statistically insignificant differences in average home values, all else being equal, between the reference group of transactions (sold in the PA period) and those similarly located more than 3 miles from the turbines but sold in the PAPC or PC periods. Those differences are estimated to be between -0.8% and -0.5%.

The results presented above, and in Table 8, include both OLS and spatial models. Prior to estimating the spatial models, the Moran's I was calculated using the residuals of an OLS model that uses the same explanatory variables as the spatial models and the same dataset (only the most recent transactions). The Moran's I statistic (0.133) was highly significant (*p*-value 0.00),

[34] p-values are not shown in the table can but can be derived from the standard errors, which are shown.

which allows us to reject the hypothesis that the residuals are spatially independent. Therefore, there was justification in estimating the spatial models. However, after estimation, we determined that only the spatial error process was significant. As a result, we estimated spatial error models (SEMs) for the final specification. The spatial autoregressive coefficient, lambda (bottom of Table 9), which is an indication of spatial autocorrelation in the residuals, is sizable and statistically significant in both SEMs (0.26, *p*-value 0.00). The SEM models' variable-of-interest coefficients are quite similar to those of the OLS models. In most cases, the coefficients are the same sign, approximately the same level, and often similarly insignificant, indicating that although spatial dependence is present it does not substantively bias the variables of interest. The one material difference is the coefficient size and significance for homes outside of 3 miles in the PAPC and PC periods, 3.3% (*p*-value 0.000) and 3.1% (*p*-value 0.008), indicating there are important changes to home values over the periods that must be accounted for in the later DD models in order to isolate the potential impacts that occur due to the presence of wind turbines.

Table 9: Results of Interacted Variables of Interest: *fdp* and *tdis*

		one-mile	*one-mile*	*half-mile*	*half-mile*
		OLS	SEM	OLS	SEM
fdp	tdis	β (se)	β (se)	β (se)	β (se)
PA	< 1 mile	-0.017	0.002		
		(0.024)	*(0.031)*		
PA	1-2 miles	-0.015	0.008		
		(0.011)	*(0.016)*		
PA	> 3 miles	Omitted	Omitted		
		n/a	*n/a*		
PAPC	< 1 mile	-0.035	-0.038		
		(0.029)	*(0.033)*		
PAPC	1-2 miles	-0.001	-0.033.		
		(0.014)	*(0.018)*		
PAPC	> 3 miles	-0.006	-0.033***		
		(0.008)	*(0.01)*		
PC	< 1 mile	0.019	-0.022		
		(0.026)	*(0.032)*		
PC	1-2 miles	0.044***	-0.001		
		(0.014)	*(0.019)*		
PC	> 3 miles	-0.005	-0.031**		
		(0.010)	*(0.012)*		
PA	< 1/2 mile			0.001	0.053
				(0.039)	*(0.045)*
PA	1/2 - 1 mile			-0.023	-0.018
				(0.027)	*(0.035)*
PA	1-2 miles			-0.015	0.008
				(0.011)	*(0.016)*
PA	> 3 miles			Omitted	Omitted
				n/a	*n/a*
PAPC	< 1/2 mile			-0.028	-0.065
				(0.049)	*(0.056)*
PAPC	1/2 - 1 mile			-0.038	-0.027
				(0.033)	*(0.036)*
PAPC	1-2 miles			-0.001	-0.034.
				(0.014)	*(0.017)*
PAPC	> 3 miles			-0.006	-0.033***
				(0.008)	*(0.009)*
PC	< 1/2 mile			-0.016	-0.036
				(0.041)	*(0.046)*
PC	1/2 - 1 mile			0.032	-0.016
				(0.031)	*(0.035)*
PC	1-2 miles			0.044***	-0.001
				(0.014)	*(0.018)*
PC	> 3 miles			-0.005	-0.031**
				(0.010)	*(0.012)*
lambda			0.247 ***		0.247 ***
			(0.008)		*(0.008)*
*Note: p-values: < 0.1 *, < 0.05 **, <0.01 ***.*					
n		51,276	38,407	51,276	38,407
adj R-sqr		0.67	0.64	0.67	0.64

5.1.3. Impact of Wind Turbines

As discussed above, there are important differences in property values between development periods for the reference group of homes (those located outside of 3 miles) that must be accounted for. Further, although they are not significant, differences between the reference category and those transactions inside of 1 mile in the PA period still must be accounted for if accurate measurements of PAPC or PC wind turbine effects are to be estimated. The DD specification accounts for both of these critical effects.

Table 10 shows the results of the DD tests across the four models, based on the results for the variables of interest presented in Table 9.[35] For example, to determine the net difference for homes that sold inside of a half mile (drawing from the *half-mile* OLS model) in the PAPC period, we use the following formula: PAPC half-mile coefficient (-0.028) less the PAPC 3-mile coefficient (-0.006) less the PA half-mile coefficient (0.001), which equals -0.024 (without rounding), which equates to 2.3% difference,[36] and is not statistically significant.

None of the DD effects in either the OLS or SEM specifications are statistically significant in the PAPC or PC periods, indicating that we do not observe a statistically significant impact of wind turbines on property values. Some small differences are apparent in the calculated coefficients, with those for PAPC being generally more negative/less positive than their PC counterparts, perhaps suggestive of a small announcement effect that declines once a facility is constructed. Further, the inside-a-half-mile coefficients are more negative/less positive than their between-a-half-and-1-mile counterparts, perhaps suggestive of a small property value impact very close to turbines.[37] However, in all cases, the sizes of these differences are smaller than the margins of error in the model (i.e., 90% confidence interval) and thus are not statistically significant. Therefore, based on these results, we do not find evidence supporting either of our two core hypotheses (*research questions 2 and 3*). In other words, there is no statistical evidence that homes in either the PAPC or PC periods that sold near turbines (i.e., within a mile or even a half

[35] All DD estimates for the OLS models were calculated using the post-estimation "lincom" test in Stata, which uses the stored results' variance/covariance matrix to test if a linear combination of coefficients is different from 0. For the SEM models, a similar test was performed in R.

[36] All differences in coefficients are converted to percentages in the table as follows: exp(coef)-1.

[37] Although not discussed in the text, this trend continues with homes between 1 and 2 miles being less negative/more positive than homes closer to the turbines (e.g., those within 1 mile).

mile) did so for less than similar homes that sold between 3 and 10 away miles in the same period.

Further, using the standard errors from the DD models we can estimate the maximum size an average effect would have to be in our sample for the model to detect it (*research question 4*). For an average effect in the PC period to be found for homes within 1 mile of the existing turbines (therefore using the *one-mile* model results), an effect greater than 4.9%, either positive or negative, would have to be present to be detected by the model.[38] In other words, it is highly unlikely that the true average effect for homes that sold in our sample area within 1 mile of an existing turbine is larger than +/-4.9%. Similarly, it is highly unlikely that the true average effect for homes that sold in our sample area within a half mile of an existing turbine is larger than +/-9.0%.[39] Regardless of these maximum effects, however, as well as the very weak suggestion of a possible small announcement effect and a possible small effect on homes that are very close to turbines, the core results of these models show effect sizes that are not statistically significant from zero, and are considerably smaller than these maximums.[40]

[38] Using the 90% confidence interval (i.e., 10% level of significance) and assuming more than 300 cases, the critical t-value is 1.65. Therefore, using the standard error of 0.030, the 90% confidence intervals for the test will be +/-0.049.

[39] Using the critical t-value of 1.66 for the 100 PC cases within a half mile in our sample and the standard error of 0.054.

[40] It is of note that these maximum effects are slightly larger than those we expected to find, as discussed earlier. This likely indicates that there was more variation in this sample, causing relatively higher standard errors for the same number of cases, than in the sample used for the 2009 study (Hoen et al., 2009, 2011).

Table 10: "Net" Difference-in-Difference Impacts of Turbines

		< 1 Mile	< 1 Mile	< 1/2 Mile	< 1/2 Mile
		OLS	SEM	OLS	SEM
fdp	tdis	b/se	b/se	b/se	b/se
PAPC	< 1 mile	-1.2% ^{NS}	-0.7% ^{NS}		
		(0.033)	*(0.037)*		
PC	< 1 mile	4.2% ^{NS}	0.7% ^{NS}		
		(0.030)	*(0.035)*		
PAPC	< 1/2 mile			-2.3% ^{NS}	-8.1% ^{NS}
				(0.060)	*(0.065)*
PAPC	1/2 - 1 mile			-0.8% ^{NS}	2.5% ^{NS}
				(0.039)	*(0.043)*
PC	< 1/2 mile			-1.2% ^{NS}	-5.6% ^{NS}
				(0.054)	*(0.057)*
PC	1/2 - 1 mile			6.3% ^{NS}	3.4% ^{NS}
				(0.036)	*(0.042)*
*Note: p-values: > 10% ^{NS}, < 10% *, < 5% **, <1 % ******					

5.2. Robustness Tests

Table 11 summarizes the results from the robustness tests. For simplicity, only the DD coefficients are shown and only for the *half-mile* OLS models.[41] The first two columns show the base OLS and SEM *half-mile* DD results (also presented earlier, in Table 9), and the remaining columns show the results from the robustness models as follows: exclusion of outliers and influential cases from the dataset (*outlier*); using sale year/county interactions instead of sale year/state (*sycounty*); using only the most recent sales instead of the most recent and prior sales (*recent*); using homes between 5 and 10 miles as the reference category, instead of homes between 3 and 10 miles (*outside5*); and using transactions occurring more than 2 years before announcement as the reference category instead of using transactions simply *before* announcement (*prior*).

[41] Results were also estimated for the *one-mile* OLS models for each of the robustness tests and are available upon request: the results do not substantively differ from what is presented here for the *half-mile* models. Because of the similarities in the results between the OLS and SEM "base" models, robustness tests on the SEM models were not prepared as we assumed that differences between the two models for the robustness tests would be minimal as well.

The robustness results have patterns similar to the base model results: none of the coefficients are statistically different from zero; all coefficients (albeit non-significant) are lower in the PAPC period than the PC period; and, all coefficients (albeit non-significant) are lower (i.e., less negative/more positive) within a half mile than outside a half mile.[42] In sum, regardless of dataset or specification, there is no change in the basic conclusions drawn from the base model results: there is no evidence that homes near operating or announced wind turbines are impacted in a statistically significant fashion. Therefore, if effects do exist, either the average impacts are relatively small (within the margin of error in the models) and/or sporadic (impacting only a small subset of homes). Moreover, these results seem to corroborate what might be predicted given the other, potentially analogous disamenity literature that was reviewed earlier, which might be read to suggest that any property value effect of wind turbines might coalesce at a maximum of 3%–4%, on average. Of course, we cannot offer that corroboration directly because, although the size of the coefficients in the models presented here are reasonably consistent with effects of that magnitude, none of our models offer results that are statistically different from zero.

[42] This trend also continues outside of 1 mile, with those coefficients being less negative/more positive than those within 1 mile.

Table 11: Robustness Half-Mile Model Results

				Robustness OLS Models				
		Base OLS	Base SEM	outlier	sycounty	recent	outside5	prior
fdp	tdis	β (se)	β (se)	β (se)	β (se)	β (se)	β (se)	β (se)
PAPC	< 1/2 mile	-2.3% ^{NS}	-8.1% ^{NS}	-4.7% ^{NS}	-4.2% ^{NS}	-5.6% ^{NS}	-1.7% ^{NS}	0.1% ^{NS}
		(0.060)	*(0.065)*	*(0.056)*	*(0.060)*	*(0.066)*	*(0.060)*	*(0.062)*
PAPC	1/2 - 1 mile	-0.8% ^{NS}	2.5% ^{NS}	-1.7% ^{NS}	-2.5% ^{NS}	2.3% ^{NS}	-0.2% ^{NS}	0.4% ^{NS}
		(0.039)	*(0.043)*	*(0.036)*	*(0.039)*	*(0.043)*	*(0.039)*	*(0.044)*
PC	< 1/2 mile	-1.2% ^{NS}	-5.6% ^{NS}	-0.5% ^{NS}	-1.8% ^{NS}	-4.3% ^{NS}	-0.3% ^{NS}	1.3% ^{NS}
		(0.054)	*(0.057)*	*(0.047)*	*(0.054)*	*(0.056)*	*(0.054)*	*(0.056)*
PC	1/2 - 1 mile	6.3% ^{NS}	3.4% ^{NS}	6.2% ^{NS}	3.8% ^{NS}	4.1% ^{NS}	7.1% ^{NS}	7.5% ^{NS}
		(0.036)	*(0.041)*	*(0.033)*	*(0.036)*	*(0.042)*	*(0.036)*	*(0.041)*
Note: p-values: > 0.1 ^{NS}*, < 0.1 *, <0.5 **, <0.01 ******								
	n	51,276	38,407	50,106	51,276	38,407	51,276	51,276
	adj R-sqr	0.67	0.64	0.66	0.67	0.66	0.67	0.67

6. Conclusion

Wind energy facilities are expected to continue to be developed in the United States. Some of this growth is expected to occur in more-populated regions, raising concerns about the effects of wind development on home values in surrounding communities.

Previous published and academic research on this topic has tended to indicate that wind facilities, after they have been constructed, produce little or no effect on home values. At the same time, some evidence has emerged indicating potential home-value effects occurring after a wind facility has been announced but before construction. These previous studies, however, have been limited by their relatively small sample sizes, particularly in relation to the important population of homes located very close to wind turbines, and have sometimes treated the variable for distance to wind turbines in a problematic fashion. Analogous studies of other disamenities—including high-voltage transmission lines, landfills, and noisy roads—suggest that if reductions in property values near turbines were to occur, they would likely be no more than 3%–4%, on average, but to discover such small effects near turbines, much larger amounts of data are needed than have been used in previous studies. Moreover, previous studies have not accounted adequately for potentially confounding home-value factors, such as those affecting home values before wind facilities were announced, nor have they adequately controlled for spatial dependence in the data, i.e., how the values and characteristics of homes located near one another influence the value of those homes (independent of the presence of wind turbines).

This study helps fill those gaps by collecting a very large data sample and analyzing it with methods that account for confounding factors and spatial dependence. We collected data from more than 50,000 home sales among 27 counties in nine states. These homes were within 10 miles of 67 different then-current or existing wind facilities, with 1,198 sales that were within 1 mile of a turbine (331 of which were within a half mile)—many more than were collected by previous research efforts. The data span the periods well before announcement of the wind facilities to well after their construction. We use OLS and spatial-process difference-in-difference hedonic models to estimate the home-value impacts of the wind facilities; these models control for value factors existing prior to the wind facilities' announcements, the spatial dependence of home values, and value changes over time. We also employ a series of robustness

models, which provide greater confidence in our results by testing the effects of data outliers and influential cases, heterogeneous inflation/deflation across regions, older sales data for multi-sale homes, the distance from turbines for homes in our reference case, and the amount of time before wind-facility announcement for homes in our reference case.

Across all model specifications, we find no statistical evidence that home prices near wind turbines were affected in either the post-construction or post-announcement/pre-construction periods. Therefore, if effects do exist, either the average impacts are relatively small (within the margin of error in the models) and/or sporadic (impacting only a small subset of homes). Related, our sample size and analytical methods enabled us to bracket the size of effects that would be detected, if those effects were present at all. Based on our results, we find that it is *highly unlikely* that the actual average effect for homes that sold in our sample area within 1 mile of an existing turbine is larger than +/-4.9%. In other words, the average value of these homes could be as much as 4.9% higher than it would have been without the presence of wind turbines, as much as 4.9% lower, the same (i.e., zero effect), or anywhere in between. Similarly, it is highly unlikely that the average actual effect for homes that sold in our sample area within a half mile of an existing turbine is larger than +/-9.0%. In other words, the average value of these homes could be as much as 9% higher than it would have been without the presence of wind turbines, as much as 9% lower, the same (i.e., zero effect), or anywhere in between.

Regardless of these potential maximum effects, the core results of our analysis consistently show no sizable statistically significant impact of wind turbines on nearby property values. The maximum impact suggested by potentially analogous disamenities (high-voltage transmission lines, landfills, roads etc.) of 3%-4% is at the far end of what the models presented in this study would have been able to discern, potentially helping to explain why no statistically significant effect was found. If effects of this size are to be discovered in future research, even larger samples of data may be required. For those interested in estimating such effects on a more micro (or local) scale, such as appraisers, these possible data requirements may be especially daunting, though it is also true that the inclusion of additional market, neighborhood, and individual property characteristics in these more-local assessments may sometimes improve model fidelity.

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8. Appendix – Full Results

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
Intercept	11.332***	(0.058)	11.330***	(0.058)	11.292***	(0.090)	11.292***	(0.090)
fdp3tdis3_11	-0.017	(0.024)			0.002	(0.031)		
fdp3tdis3_12	-0.015	(0.011)			0.008	(0.016)		
fdp3tdis3_21	-0.035	(0.029)			-0.038	(0.033)		
fdp3tdis3_22	-0.001	(0.014)			-0.033*	(0.017)		
fdp3tdis3_23	-0.006	(0.008)			-0.033***	(0.009)		
fdp3tdis3_31	0.019	(0.026)			-0.022	(0.031)		
fdp3tdis3_32	0.044***	(0.014)			-0.001	(0.018)		
fdp3tdis3_33	-0.005	(0.010)			-0.031***	(0.012)		
fdp3tdis4_10			0.001	(0.039)			0.053	(0.045)
fdp3tdis4_11			-0.023	(0.027)			-0.018	(0.035)
fdp3tdis4_12			-0.015	(0.011)			0.008	(0.016)
fdp3tdis4_20			-0.028	(0.049)			-0.065	(0.056)
fdp3tdis4_21			-0.038	(0.033)			-0.027	(0.036)
fdp3tdis4_22			-0.001	(0.014)			-0.034*	(0.017)
fdp3tdis4_23			-0.006	(0.008)			-0.033***	(0.009)
fdp3tdis4_30			-0.016	(0.041)			-0.036	(0.046)
fdp3tdis4_31			0.032	(0.031)			-0.016	(0.035)
fdp3tdis4_32			0.044***	(0.014)			-0.001	(0.018)
fdp3tdis4_33			-0.005	(0.010)			-0.031***	(0.012)
lsfla1000_ia_car	0.750***	(0.042)	0.749***	(0.042)	0.723***	(0.045)	0.722***	(0.045)
lsfla1000_ia_flo	0.899***	(0.054)	0.900***	(0.054)	0.879***	(0.060)	0.88***	(0.060)
lsfla1000_ia_fra	0.980***	(0.077)	0.980***	(0.077)	0.932***	(0.083)	0.934***	(0.083)
lsfla1000_ia_sac	0.683***	(0.061)	0.683***	(0.061)	0.633***	(0.065)	0.633***	(0.064)
lsfla1000_il_dek	0.442***	(0.037)	0.441***	(0.037)	0.382***	(0.040)	0.38***	(0.040)
lsfla1000_il_liv	0.641***	(0.030)	0.641***	(0.030)	0.643***	(0.046)	0.643***	(0.046)
lsfla1000_il_mcl	0.512***	(0.019)	0.512***	(0.019)	0.428***	(0.029)	0.428***	(0.029)
lsfla1000_mn_cot	0.800***	(0.052)	0.800***	(0.052)	0.787***	(0.077)	0.787***	(0.077)
lsfla1000_mn_fre	0.594***	(0.028)	0.595***	(0.028)	0.539***	(0.031)	0.539***	(0.031)
lsfla1000_mn_jac	0.587***	(0.101)	0.587***	(0.101)	0.551***	(0.102)	0.55***	(0.102)
lsfla1000_mn_mar	0.643***	(0.025)	0.643***	(0.025)	0.603***	(0.029)	0.603***	(0.029)
lsfla1000_nj_atl	0.421***	(0.012)	0.421***	(0.012)	0.389***	(0.014)	0.389***	(0.014)
lsfla1000_ny_cli	0.635***	(0.044)	0.635***	(0.044)	0.606***	(0.045)	0.606***	(0.045)
lsfla1000_ny_fra	0.373***	(0.092)	0.375***	(0.092)	0.433***	(0.094)	0.436***	(0.094)
lsfla1000_ny_her	0.520***	(0.034)	0.520***	(0.034)	0.559***	(0.035)	0.559***	(0.035)
lsfla1000_ny_lew	0.556***	(0.054)	0.556***	(0.054)	0.518***	(0.057)	0.518***	(0.057)
lsfla1000_ny_mad	0.503***	(0.025)	0.503***	(0.025)	0.502***	(0.025)	0.502***	(0.025)
lsfla1000_ny_ste	0.564***	(0.032)	0.564***	(0.032)	0.534***	(0.034)	0.534***	(0.034)
lsfla1000_ny_wyo	0.589***	(0.034)	0.589***	(0.034)	0.566***	(0.034)	0.566***	(0.034)
lsfla1000_oh_pau	0.625***	(0.080)	0.624***	(0.080)	0.567***	(0.090)	0.565***	(0.090)
lsfla1000_oh_woo	0.529***	(0.030)	0.529***	(0.030)	0.487***	(0.035)	0.487***	(0.035)
lsfla1000_ok_cus	0.838***	(0.037)	0.838***	(0.037)	0.794***	(0.046)	0.793***	(0.046)
lsfla1000_ok_gra	0.750***	(0.063)	0.750***	(0.063)	0.706***	(0.072)	0.706***	(0.072)
lsfla1000_pa_fay	0.332***	(0.111)	0.332***	(0.111)	0.335***	(0.118)	0.334***	(0.118)
lsfla1000_pa_som	0.564***	(0.025)	0.564***	(0.025)	0.548***	(0.031)	0.548***	(0.031)
lsfla1000_pa_way	0.486***	(0.056)	0.486***	(0.056)	0.44***	(0.063)	0.44***	(0.063)
lsfla1000_wa_kit	0.540***	(0.073)	0.540***	(0.073)	0.494***	(0.078)	0.494***	(0.078)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
acres_ia_car	0.033	(0.030)	0.033	(0.030)	0.013	(0.032)	0.013	(0.032)
acres_ia_flo	0.050***	(0.014)	0.050***	(0.014)	0.044***	(0.014)	0.044***	(0.014)
acres_ia_fra	-0.008	(0.022)	-0.008	(0.022)	-0.009	(0.022)	-0.009	(0.022)
acres_ia_sac	0.064***	(0.014)	0.064***	(0.014)	0.054***	(0.015)	0.054***	(0.015)
acres_il_dek	0.068**	(0.027)	0.064**	(0.027)	0.055*	(0.029)	0.048*	(0.029)
acres_il_liv	0.023	(0.014)	0.023	(0.014)	0.014	(0.018)	0.014	(0.018)
acres_il_mcl	0.091***	(0.010)	0.091***	(0.010)	0.092***	(0.011)	0.092***	(0.011)
acres_mn_cot	-0.030***	(0.011)	-0.030***	(0.011)	-0.024*	(0.013)	-0.024*	(0.013)
acres_mn_fre	-0.002	(0.007)	-0.002	(0.007)	0.002	(0.008)	0.002	(0.008)
acres_mn_jac	0.019	(0.016)	0.020	(0.016)	0.03*	(0.016)	0.03*	(0.016)
acres_mn_mar	0.020**	(0.008)	0.020**	(0.008)	0.017*	(0.009)	0.017*	(0.009)
acres_nj_atl	-0.041	(0.031)	-0.041	(0.031)	-0.013	(0.026)	-0.013	(0.026)
acres_ny_cli	0.019***	(0.007)	0.019***	(0.007)	0.022***	(0.007)	0.022***	(0.007)
acres_ny_fra	0.009	(0.010)	0.009	(0.010)	0.014	(0.011)	0.014	(0.011)
acres_ny_her	-0.004	(0.008)	-0.004	(0.008)	0.012	(0.008)	0.012	(0.008)
acres_ny_lew	0.014*	(0.008)	0.014*	(0.008)	0.014	(0.009)	0.014	(0.009)
acres_ny_mad	0.021***	(0.003)	0.021***	(0.003)	0.021***	(0.004)	0.021***	(0.004)
acres_ny_ste	0.009*	(0.005)	0.009*	(0.005)	0.007	(0.005)	0.007	(0.005)
acres_ny_wyo	0.016***	(0.004)	0.016***	(0.004)	0.019***	(0.004)	0.019***	(0.004)
acres_oh_pau	-0.010	(0.020)	-0.010	(0.020)	0.01	(0.024)	0.009	(0.024)
acres_oh_woo	-0.007	(0.010)	-0.007	(0.010)	0.002	(0.010)	0.002	(0.010)
acres_ok_cus	-0.037*	(0.019)	-0.037*	(0.019)	-0.034	(0.022)	-0.034	(0.022)
acres_ok_gra	0.014	(0.010)	0.014	(0.010)	0.019*	(0.011)	0.019*	(0.011)
acres_pa_fay	-0.006	(0.023)	-0.006	(0.023)	0.01	(0.023)	0.01	(0.023)
acres_pa_som	0.003	(0.009)	0.004	(0.009)	0.009	(0.010)	0.009	(0.010)
acres_pa_way	0.017**	(0.007)	0.017**	(0.007)	0.024***	(0.007)	0.024***	(0.007)
acres_wa_kit	0.009	(0.010)	0.009	(0.010)	0.014	(0.011)	0.014	(0.011)
acreslt1_ia_car	0.446***	(0.136)	0.448***	(0.136)	0.559***	(0.144)	0.56***	(0.143)
acreslt1_ia_flo	0.436***	(0.112)	0.435***	(0.112)	0.384***	(0.118)	0.383***	(0.118)
acreslt1_ia_fra	0.670***	(0.124)	0.668***	(0.124)	0.684***	(0.139)	0.68***	(0.139)
acreslt1_ia_sac	0.159	(0.115)	0.160	(0.115)	0.222*	(0.123)	0.221*	(0.123)
acreslt1_il_dek	0.278***	(0.066)	0.285***	(0.066)	0.282***	(0.073)	0.294***	(0.073)
acreslt1_il_liv	0.278***	(0.063)	0.276***	(0.063)	0.383***	(0.088)	0.38***	(0.088)
acreslt1_il_mcl	-0.069***	(0.021)	-0.070***	(0.021)	-0.007	(0.032)	-0.007	(0.032)
acreslt1_mn_cot	0.529***	(0.093)	0.529***	(0.093)	0.466***	(0.120)	0.465***	(0.120)
acreslt1_mn_fre	0.314***	(0.053)	0.314***	(0.053)	0.294***	(0.061)	0.293***	(0.061)
acreslt1_mn_jac	0.250*	(0.144)	0.247*	(0.145)	0.169	(0.146)	0.162	(0.146)
acreslt1_mn_mar	0.452***	(0.062)	0.452***	(0.062)	0.461***	(0.069)	0.462***	(0.069)
acreslt1_nj_atl	0.135***	(0.048)	0.135***	(0.048)	0.044	(0.047)	0.043	(0.047)
acreslt1_ny_cli	0.115***	(0.044)	0.115***	(0.044)	0.108**	(0.047)	0.108**	(0.047)
acreslt1_ny_fra	0.118	(0.100)	0.118	(0.100)	0.113	(0.115)	0.113	(0.115)
acreslt1_ny_her	0.364***	(0.047)	0.364***	(0.047)	0.331***	(0.050)	0.332***	(0.050)
acreslt1_ny_lew	0.119*	(0.061)	0.120**	(0.061)	0.117*	(0.067)	0.117*	(0.067)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
acreslt1_ny_mad	0.017	(0.031)	0.018	(0.031)	0.043	(0.032)	0.043	(0.032)
acreslt1_ny_ste	0.100**	(0.042)	0.100**	(0.042)	0.18***	(0.047)	0.18***	(0.047)
acreslt1_ny_wyo	0.144***	(0.035)	0.144***	(0.035)	0.137***	(0.039)	0.137***	(0.039)
acreslt1_oh_pau	0.426***	(0.087)	0.425***	(0.087)	0.507***	(0.120)	0.507***	(0.120)
acreslt1_oh_woo	0.124***	(0.034)	0.124***	(0.034)	0.114***	(0.041)	0.114***	(0.041)
acreslt1_ok_cus	0.103	(0.070)	0.104	(0.070)	0.091	(0.092)	0.093	(0.092)
acreslt1_ok_gra	-0.038	(0.054)	-0.038	(0.054)	-0.065	(0.066)	-0.065	(0.066)
acreslt1_pa_fay	0.403***	(0.153)	0.403***	(0.153)	0.42**	(0.165)	0.42**	(0.164)
acreslt1_pa_som	0.243***	(0.039)	0.243***	(0.039)	0.223***	(0.047)	0.223***	(0.047)
acreslt1_pa_way	0.138**	(0.062)	0.138**	(0.062)	0.108	(0.077)	0.109	(0.077)
acreslt1_wa_kit	0.335**	(0.134)	0.335**	(0.134)	0.342**	(0.164)	0.342**	(0.164)
age_ia_car	-0.013***	(0.001)	-0.013***	(0.001)	-0.011***	(0.001)	-0.011***	(0.001)
age_ia_flo	-0.013***	(0.002)	-0.013***	(0.002)	-0.013***	(0.002)	-0.013***	(0.002)
age_ia_fra	-0.012***	(0.003)	-0.012***	(0.003)	-0.011***	(0.003)	-0.011***	(0.003)
age_ia_sac	-0.013***	(0.003)	-0.013***	(0.003)	-0.011***	(0.003)	-0.011***	(0.003)
age_il_dek	-0.004***	(0.001)	-0.004***	(0.001)	-0.004***	(0.001)	-0.004***	(0.001)
age_il_liv	-0.001	(0.001)	-0.002	(0.001)	-0.003	(0.002)	-0.003	(0.002)
age_il_mcl	-0.004***	(0.001)	-0.004***	(0.001)	-0.006***	(0.001)	-0.006***	(0.001)
age_mn_cot	-0.021***	(0.003)	-0.021***	(0.003)	-0.013***	(0.005)	-0.013***	(0.005)
age_mn_fre	-0.013***	(0.001)	-0.013***	(0.001)	-0.012***	(0.002)	-0.012***	(0.002)
age_mn_jac	-0.018***	(0.005)	-0.018***	(0.005)	-0.018***	(0.005)	-0.018***	(0.005)
age_mn_mar	-0.010***	(0.001)	-0.010***	(0.001)	-0.009***	(0.002)	-0.009***	(0.002)
age_nj_atl	-0.004***	(0.000)	-0.004***	(0.000)	-0.003***	(0.001)	-0.003***	(0.001)
age_ny_cli	-0.005***	(0.001)	-0.005***	(0.001)	-0.005***	(0.001)	-0.005***	(0.001)
age_ny_fra	-0.004	(0.003)	-0.005	(0.003)	-0.005*	(0.003)	-0.005*	(0.003)
age_ny_her	-0.008***	(0.001)	-0.008***	(0.001)	-0.008***	(0.001)	-0.008***	(0.001)
age_ny_lew	-0.008***	(0.001)	-0.008***	(0.001)	-0.009***	(0.001)	-0.009***	(0.001)
age_ny_mad	-0.006***	(0.001)	-0.006***	(0.001)	-0.006***	(0.001)	-0.006***	(0.001)
age_ny_ste	-0.006***	(0.001)	-0.006***	(0.001)	-0.007***	(0.001)	-0.007***	(0.001)
age_ny_wyo	-0.006***	(0.001)	-0.006***	(0.001)	-0.006***	(0.001)	-0.006***	(0.001)
age_oh_pau	0.003	(0.003)	0.003	(0.003)	0.003	(0.004)	0.003	(0.004)
age_oh_woo	0.008***	(0.001)	0.008***	(0.001)	0.01***	(0.001)	0.01***	(0.001)
age_ok_cus	-0.000	(0.002)	-0.000	(0.002)	0.002	(0.003)	0.002	(0.003)
age_ok_gra	-0.000	(0.002)	-0.000	(0.002)	0.001	(0.002)	0.001	(0.002)
age_pa_fay	0.010**	(0.004)	0.010**	(0.004)	0.01**	(0.005)	0.01**	(0.005)
age_pa_som	-0.006***	(0.001)	-0.006***	(0.001)	-0.008***	(0.001)	-0.008***	(0.001)
age_pa_way	0.006***	(0.002)	0.006***	(0.002)	0.007***	(0.002)	0.007***	(0.002)
age_wa_kit	0.010***	(0.003)	0.010***	(0.003)	0.014***	(0.003)	0.014***	(0.003)
agesq_ia_car	0.034***	(0.011)	0.034***	(0.000)	0.022*	(0.012)	0.022*	(0.012)
agesq_ia_flo	0.040***	(0.016)	0.040**	(0.016)	0.044***	(0.016)	0.044***	(0.016)
agesq_ia_fra	0.025	(0.022)	0.025	(0.022)	0.02	(0.023)	0.021	(0.023)
agesq_ia_sac	0.032	(0.022)	0.032	(0.022)	0.025	(0.023)	0.025	(0.023)
agesq_il_dek	0.008	(0.010)	0.008	(0.010)	0.013	(0.012)	0.013	(0.011)
agesq_il_liv	-0.023**	(0.009)	-0.023**	(0.009)	-0.011	(0.014)	-0.011	(0.014)
agesq_il_mcl	0.005	(0.007)	0.005	(0.007)	0.021*	(0.011)	0.021*	(0.011)
agesq_mn_cot	0.109**	(0.043)	0.109**	(0.043)	0.032	(0.069)	0.033	(0.069)
agesq_mn_fre	0.046***	(0.010)	0.045***	(0.010)	0.044***	(0.012)	0.044***	(0.012)
agesq_mn_jac	0.103***	(0.035)	0.104***	(0.035)	0.1***	(0.034)	0.101***	(0.034)
agesq_mn_mar	0.012	(0.012)	0.012	(0.012)	0.006	(0.014)	0.006	(0.014)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
agesq_nj_atl	0.010***	(0.003)	0.010***	(0.003)	0.003	(0.005)	0.003	(0.005)
agesq_ny_cli	0.011*	(0.006)	0.011*	(0.006)	0.011*	(0.006)	0.011*	(0.006)
agesq_ny_fra	-0.011	(0.022)	-0.011	(0.022)	-0.002	(0.020)	-0.002	(0.020)
agesq_ny_her	0.022***	(0.005)	0.022***	(0.005)	0.022***	(0.006)	0.022***	(0.006)
agesq_ny_lew	0.031***	(0.006)	0.031***	(0.006)	0.032***	(0.007)	0.032***	(0.007)
agesq_ny_mad	0.017***	(0.003)	0.017***	(0.003)	0.023***	(0.003)	0.023***	(0.003)
agesq_ny_ste	0.013**	(0.005)	0.013**	(0.005)	0.018***	(0.005)	0.018***	(0.005)
agesq_ny_wyo	0.016***	(0.005)	0.016***	(0.005)	0.017***	(0.005)	0.017***	(0.005)
agesq_oh_pau	-0.044**	(0.022)	-0.045**	(0.022)	-0.043	(0.028)	-0.043	(0.028)
agesq_oh_woo	-0.074***	(0.007)	-0.074***	(0.007)	-0.091***	(0.009)	-0.091***	(0.009)
agesq_ok_cus	-0.091***	(0.019)	-0.091***	(0.019)	-0.113***	(0.026)	-0.113***	(0.026)
agesq_ok_gra	-0.081***	(0.023)	-0.081***	(0.023)	-0.097***	(0.029)	-0.097***	(0.029)
agesq_pa_fay	-0.112***	(0.032)	-0.112***	(0.032)	-0.105***	(0.034)	-0.106***	(0.034)
agesq_pa_som	0.000	(0.008)	0.002	(0.008)	0.016*	(0.009)	0.016*	(0.009)
agesq_pa_way	-0.000***	(0.012)	-0.052***	(0.012)	-0.053***	(0.014)	-0.053***	(0.014)
agesq_wa_kit	-0.000***	(0.027)	-0.097***	(0.027)	-0.132***	(0.031)	-0.132***	(0.031)
bathsim_ia_sac	-0.050	(0.073)	-0.050	(0.073)	-0.082	(0.077)	-0.081	(0.077)
bathsim_il_dek	-0.005	(0.015)	-0.005	(0.015)	0.001	(0.018)	0.001	(0.018)
bathsim_ny_cli	0.090***	(0.025)	0.090***	(0.025)	0.087***	(0.024)	0.087***	(0.024)
bathsim_ny_fra	0.246***	(0.062)	0.245***	(0.062)	0.213***	(0.064)	0.212***	(0.064)
bathsim_ny_her	0.099***	(0.022)	0.099***	(0.022)	0.079***	(0.022)	0.079***	(0.022)
bathsim_ny_lew	0.168***	(0.030)	0.167***	(0.030)	0.142***	(0.031)	0.142***	(0.031)
bathsim_ny_mad	0.180***	(0.014)	0.180***	(0.014)	0.157***	(0.013)	0.157***	(0.013)
bathsim_ny_ste	0.189***	(0.019)	0.189***	(0.019)	0.166***	(0.020)	0.166***	(0.020)
bathsim_ny_wyo	0.107***	(0.021)	0.107***	(0.021)	0.1***	(0.021)	0.1***	(0.021)
bathsim_oh_pau	0.095*	(0.051)	0.095*	(0.051)	0.149***	(0.057)	0.149***	(0.057)
bathsim_oh_woo	0.094***	(0.017)	0.094***	(0.017)	0.092***	(0.019)	0.092***	(0.019)
bathsim_pa_fay	0.367***	(0.077)	0.367***	(0.077)	0.301***	(0.082)	0.302***	(0.082)
bathsim_pa_way	0.082**	(0.036)	0.082**	(0.036)	0.081**	(0.041)	0.081**	(0.041)
pctvacant_ia_car	-2.515*	(1.467)	-2.521*	(1.468)	-2.011	(1.936)	-2.019	(1.937)
pctvacant_ia_flo	0.903	(1.152)	0.921	(1.152)	1.358	(1.409)	1.339	(1.410)
pctvacant_ia_fra	8.887**	(3.521)	8.928**	(3.518)	-2.596	(1.703)	-2.6	(1.703)
pctvacant_ia_sac	0.672	(0.527)	0.673	(0.527)	1.267***	(0.377)	1.266***	(0.377)
pctvacant_il_dek	0.052	(0.639)	0.062	(0.638)	0.037	(0.964)	0.069	(0.961)
pctvacant_il_liv	-0.475	(0.474)	-0.476	(0.474)	-0.699	(0.872)	-0.701	(0.872)
pctvacant_il_mcl	-0.365	(0.397)	-0.366	(0.397)	0.445	(0.670)	0.442	(0.670)
pctvacant_mn_cot	1.072*	(0.592)	1.072*	(0.592)	0.272	(1.039)	0.273	(1.039)
pctvacant_mn_fre	-1.782**	(0.703)	-1.787**	(0.703)	-1.372	(0.965)	-1.384	(0.965)
pctvacant_mn_jac	-1.345	(0.883)	-1.318	(0.884)	-1.285	(1.084)	-1.313	(1.084)
pctvacant_mn_mar	2.178***	(0.502)	2.175***	(0.502)	1.53**	(0.622)	1.528**	(0.622)
pctvacant_nj_atl	-0.054	(0.062)	-0.054	(0.062)	0.096	(0.085)	0.095	(0.085)
pctvacant_ny_cli	0.709***	(0.224)	0.709***	(0.224)	0.842***	(0.251)	0.841***	(0.251)
pctvacant_ny_fra	6.173***	(2.110)	6.104***	(2.113)	0.519	(0.710)	0.499	(0.709)
pctvacant_ny_her	-1.226***	(0.247)	-1.226***	(0.247)	-1.347***	(0.288)	-1.347***	(0.288)
pctvacant_ny_lew	-0.125	(0.127)	-0.125	(0.127)	-0.266*	(0.159)	-0.266*	(0.159)
pctvacant_ny_mad	0.750***	(0.196)	0.752***	(0.196)	0.767***	(0.246)	0.765***	(0.246)
pctvacant_ny_ste	0.280	(0.190)	0.281	(0.190)	0.039	(0.242)	0.04	(0.242)
pctvacant_ny_wyo	0.179*	(0.101)	0.178*	(0.101)	0.225*	(0.119)	0.224*	(0.119)
pctvacant_oh_pau	-1.473	(1.498)	-1.473	(1.499)	-1.341	(1.951)	-1.256	(1.952)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
pctvacant_oh_woo	-0.565	(0.400)	-0.565	(0.400)	-0.304	(0.563)	-0.306	(0.563)
pctvacant_ok_cus	-0.127	(0.358)	-0.140	(0.359)	-0.167	(0.521)	-0.189	(0.521)
pctvacant_ok_gra	1.413*	(0.777)	1.414*	(0.777)	0.537	(1.045)	0.536	(1.045)
pctvacant_pa_fay	0.227	(0.596)	0.229	(0.596)	0.232	(0.807)	0.235	(0.807)
pctvacant_pa_som	0.517***	(0.098)	0.516***	(0.098)	0.562***	(0.138)	0.562***	(0.138)
pctvacant_pa_way	0.445***	(0.156)	0.444***	(0.156)	0.446**	(0.175)	0.446**	(0.175)
pctvacant_wa_kit	-0.076	(0.546)	-0.075	(0.546)	-0.377	(0.282)	-0.377	(0.281)
pctowner_ia_car	-0.225	(0.244)	-0.225	(0.244)	-0.156	(0.324)	-0.156	(0.324)
pctowner_ia_flo	0.579**	(0.238)	0.578**	(0.238)	0.75***	(0.290)	0.75***	(0.290)
pctowner_ia_fra	0.207	(0.310)	0.206	(0.310)	0.172	(0.393)	0.169	(0.393)
pctowner_ia_sac	0.274	(0.585)	0.261	(0.586)	-0.34	(0.545)	-0.345	(0.545)
pctowner_il_dek	0.075	(0.088)	0.073	(0.087)	0.032	(0.123)	0.028	(0.123)
pctowner_il_liv	0.176	(0.140)	0.176	(0.140)	0.265	(0.200)	0.264	(0.200)
pctowner_il_mcl	0.389***	(0.051)	0.388***	(0.051)	0.331***	(0.101)	0.331***	(0.101)
pctowner_mn_cot	0.375***	(0.138)	0.375***	(0.138)	0.609**	(0.254)	0.609**	(0.254)
pctowner_mn_fre	-0.119	(0.090)	-0.120	(0.090)	-0.072	(0.124)	-0.073	(0.124)
pctowner_mn_jac	-0.206	(0.474)	-0.205	(0.474)	-0.175	(0.569)	-0.185	(0.570)
pctowner_mn_mar	0.262***	(0.076)	0.262***	(0.076)	0.151	(0.103)	0.151	(0.103)
pctowner_nj_atl	-0.087**	(0.037)	-0.087**	(0.037)	-0.036	(0.052)	-0.037	(0.052)
pctowner_ny_cli	-0.229	(0.171)	-0.229	(0.171)	-0.305	(0.199)	-0.303	(0.199)
pctowner_ny_fra	2.743*	(1.500)	2.693*	(1.505)	-0.315	(1.447)	-0.398	(1.442)
pctowner_ny_her	0.246***	(0.095)	0.246***	(0.095)	0.213*	(0.109)	0.213*	(0.109)
pctowner_ny_lew	-0.034	(0.185)	-0.034	(0.185)	-0.126	(0.219)	-0.126	(0.219)
pctowner_ny_mad	0.750***	(0.075)	0.750***	(0.075)	0.723***	(0.084)	0.723***	(0.084)
pctowner_ny_ste	0.192	(0.128)	0.191	(0.128)	-0.083	(0.162)	-0.084	(0.162)
pctowner_ny_wyo	-0.089	(0.111)	-0.089	(0.111)	-0.109	(0.138)	-0.108	(0.138)
pctowner_oh_pau	-0.187	(0.347)	-0.185	(0.348)	-1.245***	(0.473)	-1.249***	(0.474)
pctowner_oh_woo	0.263***	(0.092)	0.264***	(0.092)	0.274**	(0.136)	0.274**	(0.136)
pctowner_ok_cus	0.068	(0.104)	0.068	(0.104)	-0.041	(0.146)	-0.043	(0.146)
pctowner_ok_gra	0.271*	(0.159)	0.271*	(0.159)	0.253	(0.217)	0.253	(0.217)
pctowner_pa_fay	-0.413	(1.736)	-0.420	(1.736)	-0.15	(2.037)	-0.165	(2.037)
pctowner_pa_som	0.171	(0.114)	0.170	(0.114)	0.098	(0.173)	0.098	(0.173)
pctowner_pa_way	-0.351	(0.441)	-0.348	(0.441)	-0.251	(0.345)	-0.252	(0.345)
pctowner_wa_kit	0.257	(2.139)	0.259	(2.139)	-0.358	(1.889)	-0.361	(1.890)
med_age_ia_car	0.002	(0.002)	0.002	(0.002)	0.003	(0.003)	0.003	(0.003)
med_age_ia_flo	0.003	(0.002)	0.003	(0.002)	0.004	(0.003)	0.004	(0.003)
med_age_ia_fra	0.066***	(0.015)	0.066***	(0.015)	0.014**	(0.006)	0.014**	(0.006)
med_age_ia_sac	0.028**	(0.014)	0.028**	(0.014)	0.012	(0.010)	0.012	(0.010)
med_age_il_dek	-0.001	(0.002)	-0.001	(0.002)	-0.001	(0.003)	-0.001	(0.003)
med_age_il_liv	-0.004	(0.004)	-0.004	(0.004)	-0.005	(0.005)	-0.005	(0.005)
med_age_il_mcl	-0.006***	(0.002)	-0.006***	(0.002)	-0.006**	(0.003)	-0.006**	(0.003)
med_age_mn_cot	0.017***	(0.005)	0.017***	(0.005)	0.018**	(0.008)	0.018**	(0.008)
med_age_mn_fre	0.012***	(0.002)	0.012***	(0.002)	0.013***	(0.002)	0.013***	(0.002)
med_age_mn_jac	0.013	(0.008)	0.013	(0.008)	0.012	(0.010)	0.012	(0.010)
med_age_mn_mar	0.013***	(0.003)	0.013***	(0.003)	0.012***	(0.003)	0.012***	(0.003)
med_age_nj_atl	0.010***	(0.001)	0.010***	(0.001)	0.016***	(0.002)	0.016***	(0.002)
med_age_ny_cli	0.020***	(0.004)	0.020***	(0.004)	0.02***	(0.004)	0.02***	(0.004)
med_age_ny_fra	-0.517***	(0.198)	-0.511***	(0.198)	0.008	(0.040)	0.01	(0.039)
med_age_ny_her	0.007*	(0.003)	0.007*	(0.003)	0.005	(0.003)	0.005	(0.003)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
med_age_ny_lew	0.013***	(0.005)	0.013***	(0.005)	0.008	(0.005)	0.008	(0.005)
med_age_ny_mad	0.004**	(0.002)	0.004**	(0.002)	0.004*	(0.002)	0.004*	(0.002)
med_age_ny_ste	0.012***	(0.003)	0.012***	(0.003)	0.001	(0.004)	0.001	(0.004)
med_age_ny_wyo	0.008	(0.005)	0.007	(0.005)	0.008	(0.006)	0.008	(0.006)
med_age_oh_pau	0.034***	(0.013)	0.034***	(0.013)	0.019	(0.012)	0.019	(0.012)
med_age_oh_woo	-0.004	(0.003)	-0.004	(0.003)	-0.004	(0.004)	-0.004	(0.004)
med_age_ok_cus	0.004	(0.002)	0.004	(0.002)	0.008**	(0.004)	0.008**	(0.004)
med_age_ok_gra	0.011	(0.009)	0.011	(0.009)	0	(0.006)	0	(0.006)
med_age_pa_fay	0.049	(0.073)	0.049	(0.073)	0.052	(0.095)	0.052	(0.095)
med_age_pa_som	0.008***	(0.002)	0.008***	(0.002)	0.012***	(0.004)	0.012***	(0.004)
med_age_pa_way	-0.005	(0.012)	-0.005	(0.012)	0.002	(0.007)	0.002	(0.007)
med_age_wa_kit	-0.015	(0.095)	-0.015	(0.095)	0.025	(0.034)	0.025	(0.034)
swinter_ia	-0.034**	(0.015)	-0.034**	(0.015)	-0.039***	(0.015)	-0.039***	(0.015)
swinter_il	-0.020**	(0.008)	-0.020**	(0.008)	-0.013	(0.012)	-0.013	(0.012)
swinter_mn	-0.053***	(0.009)	-0.053***	(0.009)	-0.057***	(0.011)	-0.057***	(0.011)
swinter_nj	-0.007	(0.006)	-0.007	(0.006)	-0.008	(0.007)	-0.008	(0.007)
swinter_ny	-0.030***	(0.007)	-0.030***	(0.007)	-0.026***	(0.007)	-0.026***	(0.007)
swinter_oh	-0.048***	(0.012)	-0.048***	(0.012)	-0.055***	(0.014)	-0.055***	(0.014)
swinter_ok	-0.039**	(0.015)	-0.039**	(0.015)	-0.024	(0.018)	-0.024	(0.018)
swinter_pa	-0.025*	(0.015)	-0.025*	(0.015)	-0.02	(0.017)	-0.02	(0.017)
swinter_wa	-0.004	(0.046)	-0.004	(0.046)	0.014	(0.051)	0.013	(0.051)
sy_1996_ia	-0.436***	(0.137)	-0.433***	(0.137)	-0.493***	(0.157)	-0.489***	(0.157)
sy_1996_il	-0.267***	(0.037)	-0.267***	(0.037)	-0.344***	(0.061)	-0.344***	(0.061)
sy_1996_mn	-0.521***	(0.058)	-0.521***	(0.059)	-0.585***	(0.065)	-0.585***	(0.065)
sy_1996_nj	-0.820***	(0.022)	-0.820***	(0.022)	-0.717***	(0.038)	-0.717***	(0.038)
sy_1996_oh	-0.298***	(0.042)	-0.298***	(0.042)	-0.43***	(0.053)	-0.43***	(0.053)
sy_1996_ok	-0.444***	(0.073)	-0.444***	(0.073)	-0.846***	(0.079)	-0.846***	(0.079)
sy_1996_pa	-0.584***	(0.060)	-0.584***	(0.060)	-0.604***	(0.067)	-0.604***	(0.067)
sy_1997_il	-0.242***	(0.036)	-0.242***	(0.036)	-0.234***	(0.052)	-0.232***	(0.052)
sy_1997_mn	-0.445***	(0.055)	-0.445***	(0.055)	-0.535***	(0.060)	-0.535***	(0.060)
sy_1997_nj	-0.791***	(0.021)	-0.791***	(0.021)	-0.686***	(0.038)	-0.686***	(0.038)
sy_1997_oh	-0.302***	(0.043)	-0.302***	(0.043)	-0.39***	(0.053)	-0.39***	(0.053)
sy_1997_pa	-0.458***	(0.057)	-0.458***	(0.057)	-0.51***	(0.066)	-0.51***	(0.066)
sy_1998_ia	-0.442***	(0.078)	-0.441***	(0.078)	-0.633***	(0.099)	-0.634***	(0.099)
sy_1998_il	-0.156***	(0.031)	-0.156***	(0.031)	-0.175***	(0.048)	-0.175***	(0.048)
sy_1998_mn	-0.391***	(0.054)	-0.391***	(0.054)	-0.484***	(0.059)	-0.484***	(0.059)
sy_1998_nj	-0.723***	(0.020)	-0.723***	(0.021)	-0.633***	(0.037)	-0.633***	(0.037)
sy_1998_oh	-0.217***	(0.040)	-0.217***	(0.040)	-0.302***	(0.047)	-0.302***	(0.047)
sy_1998_ok	-0.394***	(0.048)	-0.395***	(0.048)	-0.816***	(0.059)	-0.818***	(0.059)
sy_1998_pa	-0.481***	(0.059)	-0.480***	(0.059)	-0.554***	(0.068)	-0.552***	(0.067)
sy_1998_wa	-0.433***	(0.115)	-0.433***	(0.115)	-0.356**	(0.161)	-0.356**	(0.161)
sy_1999_ia	-0.347***	(0.085)	-0.345***	(0.086)	-0.568***	(0.117)	-0.565***	(0.117)
sy_1999_il	-0.155***	(0.031)	-0.156***	(0.031)	-0.215***	(0.046)	-0.214***	(0.046)
sy_1999_mn	-0.302***	(0.055)	-0.303***	(0.055)	-0.367***	(0.059)	-0.368***	(0.059)
sy_1999_nj	-0.679***	(0.020)	-0.679***	(0.020)	-0.583***	(0.036)	-0.583***	(0.036)
sy_1999_oh	-0.161***	(0.040)	-0.161***	(0.040)	-0.243***	(0.047)	-0.243***	(0.047)
sy_1999_ok	-0.347***	(0.044)	-0.348***	(0.044)	-0.743***	(0.050)	-0.743***	(0.050)
sy_1999_pa	-0.452***	(0.058)	-0.452***	(0.058)	-0.515***	(0.066)	-0.515***	(0.066)
sy_1999_wa	-0.432***	(0.114)	-0.432***	(0.114)	-0.454***	(0.166)	-0.453***	(0.165)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
sy_2000_ia	-0.165	(0.145)	-0.164	(0.146)	-0.246	(0.183)	-0.246	(0.183)
sy_2000_il	-0.088***	(0.031)	-0.088***	(0.031)	-0.172***	(0.045)	-0.171***	(0.045)
sy_2000_mn	-0.148***	(0.051)	-0.149***	(0.051)	-0.224***	(0.053)	-0.224***	(0.053)
sy_2000_nj	-0.565***	(0.020)	-0.565***	(0.020)	-0.461***	(0.036)	-0.462***	(0.036)
sy_2000_oh	-0.098**	(0.041)	-0.098**	(0.041)	-0.161***	(0.047)	-0.16***	(0.047)
sy_2000_ok	-0.330***	(0.050)	-0.331***	(0.050)	-0.748***	(0.059)	-0.749***	(0.059)
sy_2000_pa	-0.394***	(0.057)	-0.395***	(0.057)	-0.478***	(0.067)	-0.478***	(0.067)
sy_2000_wa	-0.463***	(0.115)	-0.463***	(0.115)	-0.403**	(0.160)	-0.402**	(0.160)
sy_2001_ia	-0.334***	(0.065)	-0.332***	(0.065)	-0.435***	(0.066)	-0.433***	(0.066)
sy_2001_il	-0.080**	(0.031)	-0.080***	(0.031)	-0.101**	(0.048)	-0.101**	(0.048)
sy_2001_mn	-0.119**	(0.050)	-0.119**	(0.050)	-0.204***	(0.051)	-0.204***	(0.052)
sy_2001_nj	-0.438***	(0.018)	-0.438***	(0.018)	-0.333***	(0.034)	-0.333***	(0.034)
sy_2001_oh	-0.033	(0.036)	-0.033	(0.036)	-0.078**	(0.040)	-0.078**	(0.040)
sy_2001_ok	-0.250***	(0.041)	-0.251***	(0.041)	-0.648***	(0.044)	-0.648***	(0.044)
sy_2001_pa	-0.402***	(0.055)	-0.402***	(0.055)	-0.446***	(0.063)	-0.447***	(0.063)
sy_2001_wa	-0.378***	(0.122)	-0.378***	(0.122)	-0.275*	(0.163)	-0.275*	(0.163)
sy_2002_ia	-0.130**	(0.059)	-0.128**	(0.059)	-0.264***	(0.064)	-0.261***	(0.064)
sy_2002_il	0.008	(0.030)	0.007	(0.030)	-0.013	(0.043)	-0.013	(0.043)
sy_2002_mn	-0.072	(0.050)	-0.072	(0.050)	-0.138***	(0.051)	-0.139***	(0.051)
sy_2002_nj	-0.330***	(0.019)	-0.330***	(0.019)	-0.195***	(0.035)	-0.195***	(0.035)
sy_2002_ny	-0.307***	(0.020)	-0.307***	(0.020)	-0.342***	(0.020)	-0.342***	(0.020)
sy_2002_oh	-0.022	(0.038)	-0.022	(0.038)	-0.053	(0.042)	-0.053	(0.042)
sy_2002_ok	-0.249***	(0.045)	-0.249***	(0.045)	-0.649***	(0.052)	-0.649***	(0.052)
sy_2002_pa	-0.313***	(0.053)	-0.313***	(0.053)	-0.355***	(0.059)	-0.354***	(0.059)
sy_2002_wa	-0.241**	(0.123)	-0.241**	(0.123)	-0.216	(0.166)	-0.216	(0.166)
sy_2003_ia	-0.195**	(0.081)	-0.194**	(0.081)	-0.311***	(0.085)	-0.314***	(0.084)
sy_2003_il	0.034	(0.030)	0.034	(0.030)	0.021	(0.040)	0.021	(0.040)
sy_2003_mn	0.034	(0.049)	0.034	(0.049)	-0.026	(0.049)	-0.026	(0.049)
sy_2003_nj	-0.119***	(0.017)	-0.119***	(0.017)	0.023	(0.033)	0.023	(0.033)
sy_2003_ny	-0.247***	(0.020)	-0.247***	(0.020)	-0.276***	(0.020)	-0.276***	(0.020)
sy_2003_oh	0.005	(0.036)	0.005	(0.036)	-0.019	(0.039)	-0.019	(0.039)
sy_2003_ok	-0.229***	(0.046)	-0.229***	(0.046)	-0.632***	(0.053)	-0.632***	(0.053)
sy_2003_pa	-0.191***	(0.052)	-0.191***	(0.052)	-0.213***	(0.054)	-0.213***	(0.054)
sy_2003_wa	-0.326***	(0.114)	-0.326***	(0.114)	-0.335**	(0.159)	-0.337**	(0.159)
sy_2004_ia	-0.209***	(0.076)	-0.208***	(0.076)	-0.307***	(0.087)	-0.308***	(0.087)
sy_2004_il	0.087***	(0.029)	0.087***	(0.029)	0.105***	(0.034)	0.105***	(0.034)
sy_2004_mn	0.082*	(0.049)	0.081*	(0.049)	0.036	(0.049)	0.036	(0.049)
sy_2004_ny	-0.179***	(0.019)	-0.179***	(0.019)	-0.2***	(0.020)	-0.2***	(0.020)
sy_2004_oh	0.059	(0.037)	0.059	(0.037)	0.067*	(0.039)	0.067*	(0.039)
sy_2004_ok	-0.143***	(0.041)	-0.143***	(0.041)	-0.511***	(0.044)	-0.511***	(0.044)
sy_2004_pa	-0.146***	(0.052)	-0.146***	(0.052)	-0.145***	(0.053)	-0.145***	(0.053)
sy_2004_wa	-0.144	(0.113)	-0.144	(0.113)	-0.082	(0.152)	-0.081	(0.152)
sy_2005_ia	-0.074**	(0.037)	-0.075**	(0.037)	-0.151***	(0.040)	-0.151***	(0.040)
sy_2005_il	0.125***	(0.027)	0.125***	(0.027)	0.139***	(0.032)	0.138***	(0.032)
sy_2005_mn	0.163***	(0.048)	0.162***	(0.048)	0.12**	(0.048)	0.119**	(0.048)
sy_2005_nj	0.278***	(0.018)	0.278***	(0.018)	0.453***	(0.034)	0.453***	(0.034)
sy_2005_ny	-0.110***	(0.019)	-0.111***	(0.019)	-0.122***	(0.019)	-0.122***	(0.019)
sy_2005_oh	0.112***	(0.036)	0.112***	(0.036)	0.099***	(0.037)	0.098***	(0.037)
sy_2005_ok	-0.018	(0.038)	-0.018	(0.038)	-0.354***	(0.038)	-0.354***	(0.038)

	OneMile OLS		HalfMile OLS		OneMile SEM		HalfMile SEM	
Variables	**coef**	**se**	**coef**	**se**	**coef**	**se**	**coef**	**se**
sy_2005_pa	-0.060	(0.051)	-0.060	(0.051)	-0.058	(0.053)	-0.058	(0.053)
sy_2005_wa	-0.070	(0.111)	-0.070	(0.111)	0.025	(0.153)	0.025	(0.153)
sy_2006_ia	-0.050*	(0.028)	-0.051*	(0.028)	-0.106***	(0.028)	-0.106***	(0.028)
sy_2006_il	0.192***	(0.026)	0.192***	(0.026)	0.215***	(0.030)	0.215***	(0.030)
sy_2006_mn	0.206***	(0.049)	0.206***	(0.049)	0.164***	(0.049)	0.164***	(0.049)
sy_2006_nj	0.340***	(0.017)	0.340***	(0.017)	0.514***	(0.032)	0.514***	(0.032)
sy_2006_ny	-0.066***	(0.019)	-0.066***	(0.019)	-0.073***	(0.019)	-0.073***	(0.019)
sy_2006_oh	0.147***	(0.034)	0.147***	(0.034)	0.144***	(0.035)	0.144***	(0.035)
sy_2006_ok	0.025	(0.039)	0.026	(0.039)	-0.3***	(0.037)	-0.3***	(0.037)
sy_2006_pa	0.008	(0.051)	0.008	(0.051)	-0.001	(0.052)	-0.001	(0.052)
sy_2006_wa	-0.066	(0.131)	-0.066	(0.131)	0.02	(0.160)	0.021	(0.160)
sy_2007_ia	0.013	(0.028)	0.012	(0.028)	-0.019	(0.028)	-0.019	(0.028)
sy_2007_il	0.218***	(0.025)	0.218***	(0.025)	0.251***	(0.028)	0.251***	(0.028)
sy_2007_mn	0.177***	(0.049)	0.177***	(0.049)	0.145***	(0.048)	0.144***	(0.048)
sy_2007_nj	0.297***	(0.017)	0.297***	(0.017)	0.459***	(0.031)	0.459***	(0.031)
sy_2007_ny	-0.020	(0.019)	-0.020	(0.019)	-0.022	(0.019)	-0.022	(0.019)
sy_2007_oh	0.144***	(0.035)	0.143***	(0.035)	0.138***	(0.036)	0.138***	(0.036)
sy_2007_ok	0.149***	(0.037)	0.150***	(0.037)	-0.154***	(0.034)	-0.154***	(0.034)
sy_2007_pa	0.030	(0.051)	0.030	(0.051)	0.067	(0.052)	0.067	(0.052)
sy_2007_wa	0.189*	(0.110)	0.189*	(0.110)	0.209	(0.147)	0.209	(0.147)
sy_2008_ia	0.011	(0.029)	0.010	(0.029)	-0.029	(0.029)	-0.029	(0.029)
sy_2008_il	0.219***	(0.026)	0.218***	(0.026)	0.217***	(0.029)	0.217***	(0.029)
sy_2008_mn	0.149***	(0.050)	0.149***	(0.050)	0.108**	(0.049)	0.108**	(0.049)
sy_2008_nj	0.195***	(0.018)	0.195***	(0.018)	0.35***	(0.032)	0.35***	(0.032)
sy_2008_ny	-0.000	(0.019)	-0.000	(0.019)	-0.008	(0.019)	-0.008	(0.019)
sy_2008_oh	0.084**	(0.036)	0.084**	(0.036)	0.061*	(0.037)	0.061*	(0.037)
sy_2008_ok	0.154***	(0.039)	0.153***	(0.039)	-0.145***	(0.035)	-0.145***	(0.035)
sy_2008_pa	0.044	(0.053)	0.044	(0.053)	0.055	(0.053)	0.056	(0.053)
sy_2008_wa	0.178	(0.117)	0.179	(0.117)	0.326**	(0.148)	0.325**	(0.148)
sy_2009_ia	-0.056	(0.036)	-0.057	(0.036)	-0.102***	(0.036)	-0.102***	(0.036)
sy_2009_il	0.158***	(0.026)	0.158***	(0.026)	0.176***	(0.028)	0.176***	(0.028)
sy_2009_mn	0.104**	(0.051)	0.104**	(0.051)	0.089*	(0.050)	0.089*	(0.050)
sy_2009_nj	0.071***	(0.019)	0.071***	(0.019)	0.238***	(0.032)	0.238***	(0.032)
sy_2009_ny	-0.005	(0.019)	-0.005	(0.019)	-0.013	(0.019)	-0.013	(0.019)
sy_2009_oh	0.036	(0.035)	0.036	(0.035)	0.028	(0.036)	0.028	(0.036)
sy_2009_ok	0.219***	(0.038)	0.219***	(0.038)	-0.102***	(0.034)	-0.101***	(0.034)
sy_2009_pa	0.009	(0.053)	0.010	(0.053)	0.0003	(0.054)	0.0004	(0.054)
sy_2010_ia	0.018	(0.029)	0.017	(0.029)	-0.004	(0.028)	-0.004	(0.028)
sy_2010_il	0.105***	(0.028)	0.105***	(0.028)	0.104***	(0.029)	0.104***	(0.029)
sy_2010_mn	0.181***	(0.050)	0.180***	(0.050)	0.137***	(0.049)	0.137***	(0.049)
sy_2010_nj	0.010	(0.019)	0.010	(0.019)	0.177***	(0.032)	0.178***	(0.032)
sy_2010_ny	0.003	(0.021)	0.003	(0.021)	-0.006	(0.020)	-0.006	(0.020)
sy_2010_oh	-0.017	(0.036)	-0.017	(0.036)	-0.024	(0.036)	-0.024	(0.036)
sy_2010_ok	0.231***	(0.038)	0.231***	(0.038)	-0.074**	(0.033)	-0.074**	(0.033)
sy_2010_pa	0.013	(0.057)	0.013	(0.057)	0.013	(0.057)	0.013	(0.057)
sy_2010_wa	0.207	(0.127)	0.207	(0.127)	0.305*	(0.165)	0.305*	(0.165)
note: *** p<0.01, ** p<0.05, * p<0.1								
N	51,276		51,276		38,407		38,407	
Adjusted R^2	0.66		0.66		0.64		0.64	

ELECTRICITY PRICES AND INCENTIVES

APEX CLEAN ENERGY

CONTROLLING YOUR ELECTRICITY BILL

For a wind energy project to be successful, there must be a buyer for the power it will produce. Generally, this electricity is purchased by utilities, manufacturers, universities, or municipalities that demand large amounts of energy.

These large-scale customers buy wind power because:

- Unlike coal, gas, and other fuels, the cost of wind doesn't change. The fuel for wind energy is free.
- Once a project is built, the cost of producing energy remains constant, so power purchase contracts "lock in" a predictable, steady rate for 20 to 25 years.

Wind Is Price Competitive

In many locations, the cost of wind power is already competitive with other energy sources. In fact, in some parts of the country, consumers are saving significant sums of money because utilities are buying power from wind energy projects.

"Wind energy costs are lower than ever, with steady advances in technology and better wind turbine performance."

—U.S. Department of Energy (DOE)

Wind Power Installation Is Increasing Substantially

Wind power constituted 27% of all capacity additions in 2016. Over the last decade, wind represented 31% of all U.S. capacity additions, and an even larger fraction of new capacity in the Interior (56%) and Great Lakes (48%) regions.*

Wind Energy and Tax Incentives

Tax incentives to encourage domestic energy production are nothing new. Some oil industry tax incentives are over 100 years old. Incentives have played a major role in developing new technologies that have reduced natural gas prices and commercialized shale-oil production, helping to drive America's current energy boom.

"Wind capacity additions continued at a rapid pace in 2016, with significant additional new builds anticipated over the next four years."

— U.S. Department of Energy, 2016 Wind Technologies Market Report

The Renewable Electricity Production Tax Credit (PTC) is an income tax credit of 2.2 cents per kWh for electricity from wind turbines. Unlike a grant or direct payment to wind energy companies, the PTC reduces income tax for wind project owners based on the amount of energy produced in the first 10 years of operation. This savings allows a project to charge lower rates for its energy. Thus, like all energy incentives, the PTC helps save money for consumers while also creating American jobs in construction, turbine component manufacturing, supply industries, trucking companies, and more.

*U.S. Department of Energy, *2016 Wind Technologies Market Report*

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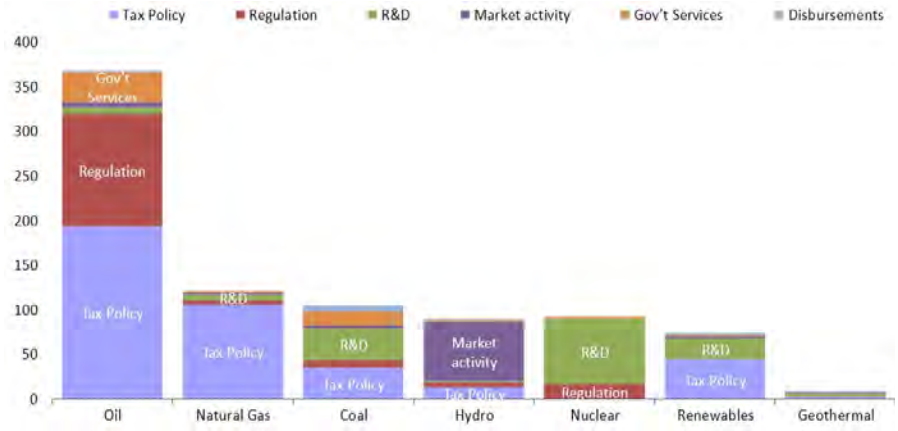
ENERGY INCENTIVES FACTS

Energy subsidies are not new

For nearly a century, oil and gas have had major incentives for domestic production. Incentives for wind energy have just recently started and are only enacted for a short period of time. The primary purpose of incentives is to encourage investment in technologies that have public benefits. Wind energy, as a clean technology that helps diversify our energy mix, has many public benefits worth incentivizing.



Production Tax Credit (PTC) facts

The PTC is a federal incentive that provides financial support for the development of renewable energy facilities. The PTC provided renewable companies with a 2.3-cent per kilowatt-hour (kWh) incentive for the first ten years of a renewable energy facility's operation. The PTC has allowed for many economic benefits including:

- From 2007-2014, the U.S. wind capacity has nearly quadrupled, representing an annual investment of $15 billion
- The cost of generating electricity from wind has fallen by more than 40 percent over the past three years
- More than 550 manufacturing facilities located in 43 states produce 70 percent of the wind turbines and components installed in the United States, up from 20 percent in 2006-2007

"For more than half a century, federal energy tax policy focused almost exclusively on increasing domestic oil and gas reserves production. There were no major tax incentives promoting renewable energy or energy efficiency."

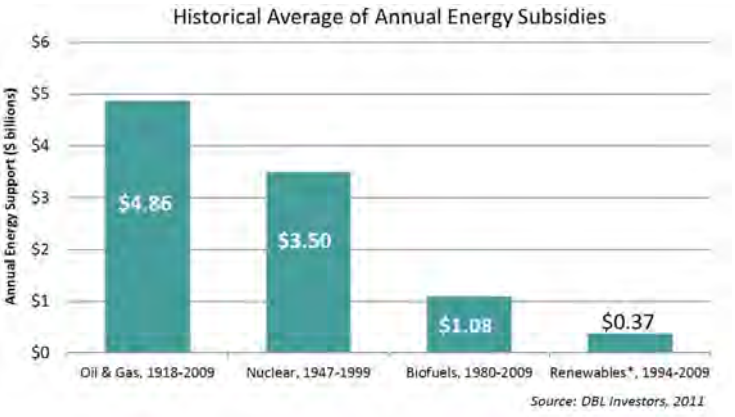
-Congressional Research Service

Incentives Statistics

When looking at the chart, it is important to notice the facts:

- Fossil fuels have been given $447 billion in incentives
- $185.5 billion for nuclear
- $6 billion for renewables

Renewables therefore account for less than 1 percent of the total amount given to fossil and nuclear.



Wind energy has more benefits

Wind energy protects the environment, consumers and public health.

Wind energy creates economic value by drastically reducing pollution that harms public health and the environment. Wind energy also protects consumers from price increases for fuel. The wind industry continues to make tremendous progress that has reduced costs by more than half over the last five years, even with the uncertain policies.

Theel, S. (2015, March 17). Into the Wind: AWEA Blog. Retrieved from Missing the big picture on energy subsidies: http://www.aweablog.org/missing-the-big-picture-on-energy-subsidies/

APEX CLEAN ENERGY

American wind power now generates over 10 percent of electricity in nine states

In Iowa and South Dakota, wind energy is more than one-ffth of total energy production

March 13, 2013

WASHINGTON, D.C., March 13, 2013 – The American wind industry experienced record-breaking growth in 2012 as a U.S. power provider. American wind power's generation shot up 17 percent last year, and produced more than 10 percent of the electricity in nine states, up from five states in 2011. Those numbers are likely to continue growing as new investments and wind projects are announced. Across the country, wind energy produced 3.5 percent of the nation's electricity during 2012, according to the Energy Information Admiration's (EIA) latest figures.

"With wind power serving as the number one source of new generating capacity in 2012, it's no surprise that wind energy is increasing its role in the overall U.S. power mix," said Elizabeth Salerno, Director of Industry Data & Analysis at the American Wind Energy Association (AWEA).

The growth in wind energy in the U.S. can also be seen in its increasing role in the generation mix of individual states. Iowa and South Dakota reached generation levels greater than 20 percent throughout the entire year of 2012. In a total of 14 states, American wind energy provides 5 percent or more of generation.

Iowa was ranked first in wind generation, with 24.5% generation from wind energy. South Dakota was a close second with 23.9% generation from wind energy. North Dakota ranked third Minnesota closely followed, ranking fourth with over 14% wind energy generation. Kansas, which doubled its installation of wind power during 2012, jumped ahead to No. 5 position in wind generation, surpassing the 10% mark, reaching 11.4% generation from wind energy.

Percent of electric power from wind generation by state

Top 20 States during 2012

Rank	State	% Wind Generation in 2012	Rank	State	% Wind Generation in 2012
1	Iowa	24.5%	11	Texas	7.4%
2	South Dakota	23.9%	12	New Mexico	6.1%
3	North Dakota	14.7%	13	Maine	5.9%
4	Minnesota	14.3%	14	Washington	5.8%
5	Kansas	11.4%	15	California	4.9%
6	Colorado	11.3%	16	Montana	4.5%
7	Idaho	11.3%	17	Illinois	3.9%
8	Oklahoma	10.5%	18	Nebraska	3.7%
9	Oregon	10.0%	19	Hawaii	3.6%
10	Wyoming	8.8%	20	Indiana	2.8%

"We are generating enough clean, affordable, American wind energy to power the equivalent of almost 15 million homes, or the number in Colorado, Iowa, Maryland, Michigan, Nevada, and Ohio combined," continued Salerno.

The geographic diversity and abundance of American wind installations is a reflection of the United States' strong wind resource. In a 2010 study, the National Renewable Energy Laboratory reported over 10 million MW of wind resource in the U.S., enough to power the equivalent of the nation's total electricity needs 10 times over. In fact, 25 states have enough wind potential to supply as much electricity as is currently generated from all energy sources in their state.

Texas, the state that uses the most electricity, relied on wind energy for 9.2% of the electrical generation last year on the Electric Reliability Council of Texas (ERCOT) power grid. The Lone Star State boasts more wind power than any other state, with more than 12,000 MW installed – over a fifth of the 60,000 MW in the United States at the end of last year.

Overall, the U.S. wind energy industry had its strongest year ever in 2012, installing a record 13,124 megawatts (MW) of electric generating capacity, leveraging $25 billion in private investment, and achieving over 60,000 MW of cumulative wind capacity.

In this historic year of achievement, wind energy for the first time became the number one source of new U.S. electric generating capacity, providing some 42 percent of all new generating capacity. Renewable energy as a whole accounted for over 55 percent of all new U.S. generating capacity in 2012.

Note: The statistics count megawatt-hours generated in a state as going to that state. For a state like California, which may be importing wind, these totals are lower than the total renewable energy used to comply with the state's Renewable Portfolio Standard.

AWEA is the national trade association of the U.S. wind energy industry. We represent 1,000 member companies and over 100,000 jobs in the U.S. economy, serving as a powerful voice for how wind works for America. Members include global leaders in wind power and energy development, turbine manufacturing, and component and service suppliers. They gather each year at the Western Hemisphere's largest wind power trade show, the AWEA WINDPOWER Conference & Exhibition, next in Chicago, Illinois, May 7-10, 2018. Find information about wind energy on the AWEA website. Gain insight into industry issues on AWEA's blog, Into the Wind. And please join us on Facebook, and follow @AWEA on Twitter.

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Wind Power Is Reducing Electricity Rates; Pays Back Tax Credit 17 Times Over

by Andrew Burger on Monday, Apr 7th, 2014

Higher performance turbines, lower manufacturing costs and lower prices for consumers drove new U.S. wind energy construction to record heights in early 2014 — despite the U.S. Congress still debating whether or not to renew the federal renewable energy production tax credit (PTC), which expired Dec. 31. In many parts of the U.S., wind energy is now the cheapest form of electricity generation – cheaper than natural gas and even coal, NextEra chief financial office Moray P. Dewhurst recently stated on an earnings call.

The federal wind energy PTC has been instrumental in the U.S. wind energy industry achieving that milestone. Yet, Congress has been playing “now-you-see-it-now-you-don’t” with the U.S. wind energy industry for two decades now. Every time the PTC expires, wind energy investment and new capacity tumbles; when it’s in place, wind energy booms. It’s just bad policy, emblematic of the divisive partisanship, cronyism, lack of foresight and political leadership that has come to characterize U.S. politics.

In its “Outlook for Renewable Energy 2014,” the American Council on Renewable Energy(ACORE), working in conjunction with U.S. renewable energy industry trade associations, presents facts and figures that clearly illustrate the triple-bottom-line benefits and advantages the U.S. wind energy industry brings to American society, and how the renewable energy PTC has played a seminal role in spurring them on to realization.

Wind energy: Cheapest energy source in the U.S.

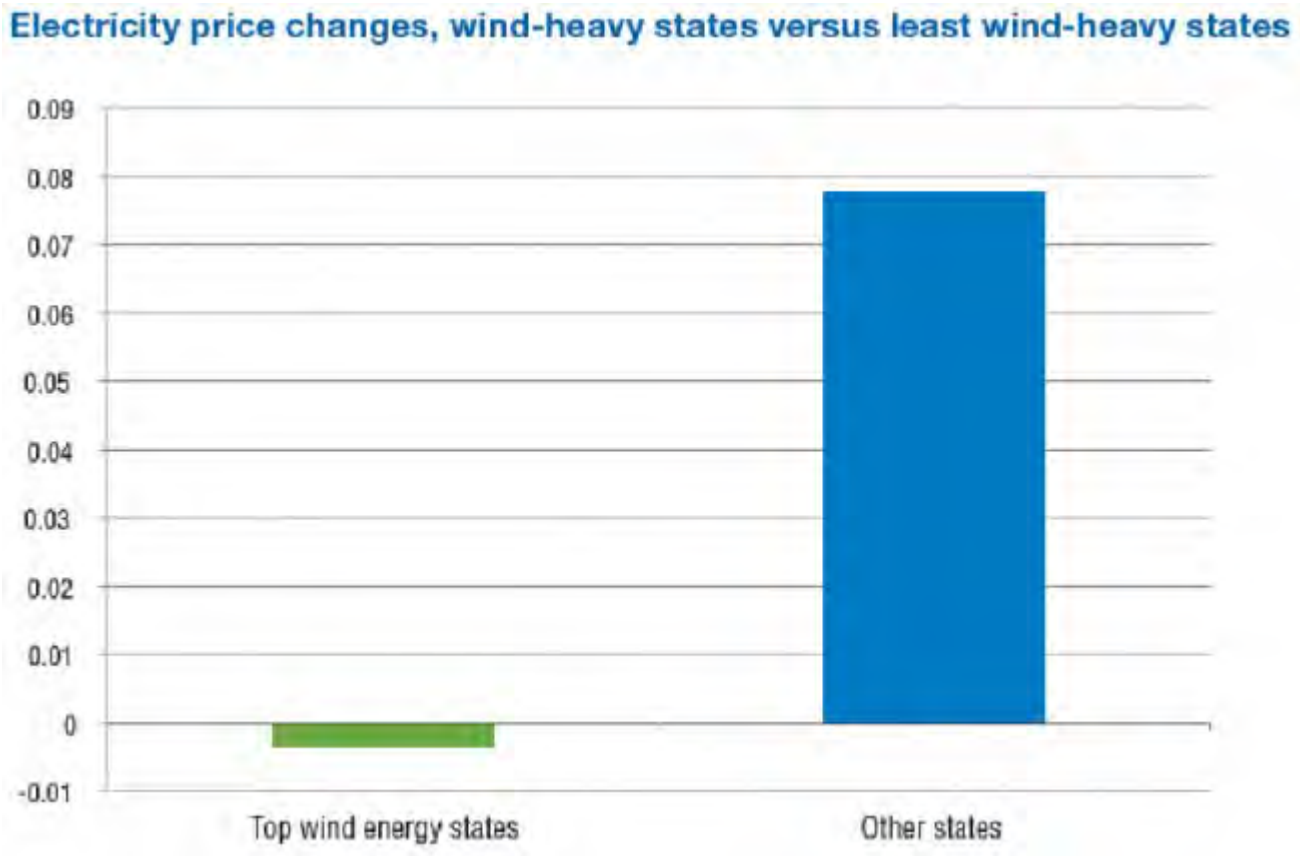
Faced with the increasingly urgent need to wean ourselves off fossil fuels and build a new clean energy infrastructure for the 21st century and beyond, members of Congress continue to oppose clean, renewable energy policies that carry tremendous, clearly demonstrated economic, social and environmental benefits and advantages. They also continue to support subsidies and incentives for one of the most profitable, dangerously polluting and politically powerful lobbies in U.S. history – the oil and gas industry.

The first section of ACORE’s “Outlook for Renewable Energy 2014” on the U.S. wind energy sector very clearly and concisely makes the case as to why the wind energy industry more than merits the support of the federal, as well as state and local, governments.

Now the cheapest means of generating electricity in many parts of the country, net power generation from wind energy was up 19 percent year-over-year in 2014, meeting 4.13 percent of U.S. grid demand, according to ACORE and the American Wind Energy Association (AWEA). Among U.S. states, 27.38 percent of Iowa, 25.95 percent of South Dakota and 19.39 percent of Kansas’s electricity came from wind energy in 2013.

Not only is wind energy lowering electricity rates, the prices consumers are paying in parts of the country where wind-generated electricity isn't being added to the grid are going up. As ACORE highlights,

"The 11 states that produce more than 7 percent of their electricity from wind energy have seen their electricity prices fall by 0.37 percent over the last five years, while all other states have seen their electricity prices increase by 7.79 percent over that period. This is clear evidence for wind energy's impact on keeping consumers' electricity prices down."

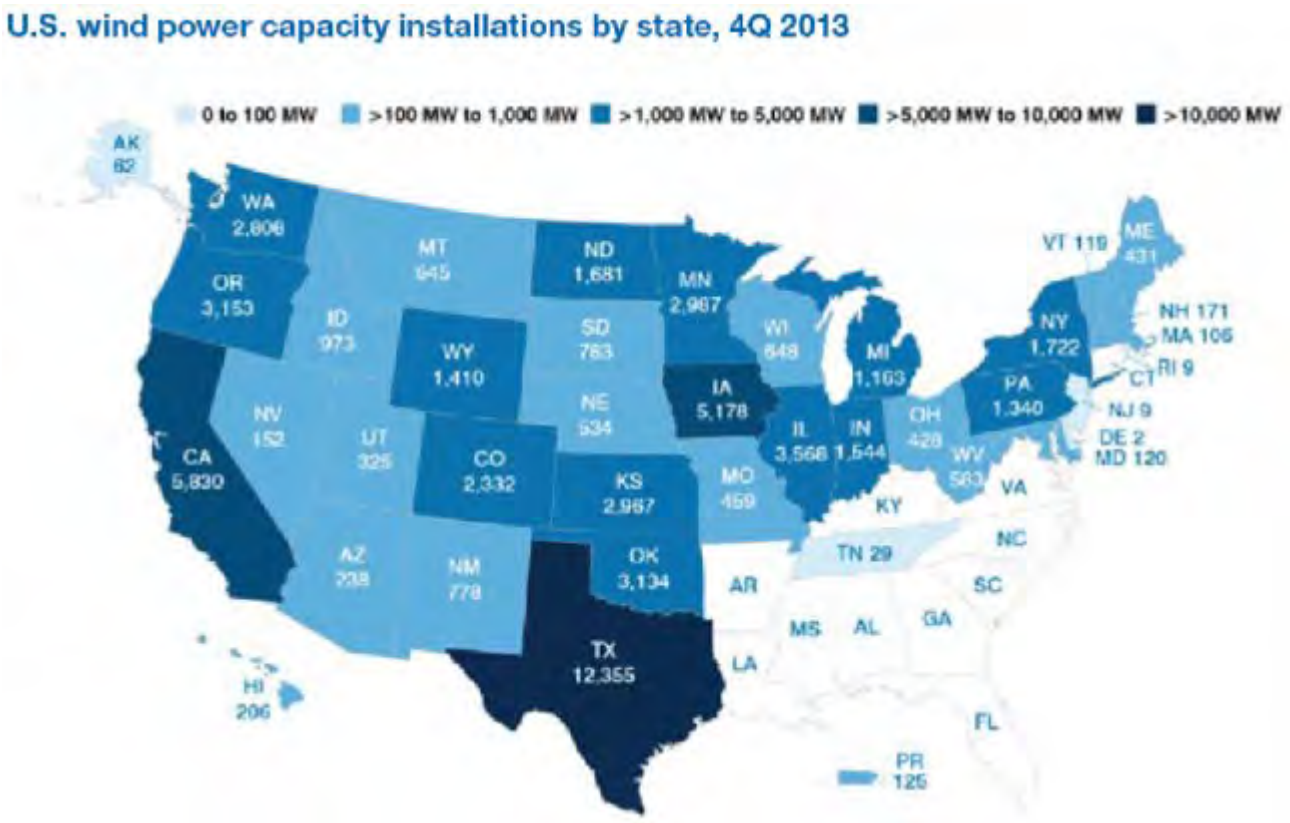


A record of more than 10,900 megawatts (MW) of new wind power capacity began construction, and more than 12,000 MW were under construction in last year's fourth quarter — just ahead of expiration of the wind energy PTC. Upon completion, these 90-plus projects will generate

enough clean, renewable electricity to supply another 3.5 million households, according to ACORE.

Last year also marked important developments in the nascent U.S. offshore wind energy industry. As ACORE highlights, in addition to the University of Maine's DeepCwind Consortium launching a pilot project, the U.S. Department of the Interior (DOI) held auctions for ocean areas off Rhode Island, Massachusetts and Virginia. Maryland passed legislation to support 200 MW of offshore wind power, while the U.S. Department of Energy (DOE) continued its groundbreaking work on seven offshore wind power demonstration projects.

Overall wind energy costs have fallen 43 percent in four years. Driven by advances in technology and stable, supportive policy, wind has been set on a pace to supply 20 percent of U.S. power grid needs by 2030, ACORE continues in its latest annual outlook for the U.S. renewable energy industry.



Wind energy PTC's outsized returns

Moreover, the wind energy PTC attracted $25 billion in private sector investment in one year – 17 times the current annual value of the tax credit, ACORE highlights. As Morgan Stanley's chairman of institutional securities Jeffrey Holzschuh added in a press release:

"The financial markets have responded to greater American consumer interest in renewable energy with increasing levels of private sector investment. Spurred by growing individual as well as business demand, private sector investment in the U.S. clean energy sector surpassed $100 billion in 2012-2013, stimulating significant economic development while supporting hundreds of thousands of jobs."

That $25 billion single-year total is long-term private sector capital expenditure that likely would not have occurred had the PTC not been in

place. And, as Morgan Stanley's Holzschuh highlighted, that's generating well-paying green jobs — lots of them. More than 70 percent of the value of wind turbines in the U.S. now carry the "Made-in-the-USA" label, ACORE notes.

Wind power, climate change and the water-energy nexus

There are yet more benefits and economic, social and environmental advantages to making use of wind energy. The wind that fuels this clean, renewable source of electricity generation is free once construction costs and ongoing operating and maintenance costs are recovered. As ACORE points out:

"Zero-fuel-cost wind energy directly displaces the output of the most expensive and least efficient power plants currently operating."

According to market rules, grid operators add electricity to the grid in response to demand based only on the fuel costs and variable operations and maintenance costs of generation sources. Hence, wind and other zero-fuel-cost generating sources, such as solar, always rank first and displace more expensive power sources.

As a result, wind, solar and other such zero-cost-fuels are yielding very real social and environmental benefits in that they push the least efficient fossil-fuel power plants out of the market. That's not only reducing the cost of electricity, it's reducing air, land and water pollution, as well as carbon and greenhouse gas emissions. That mitigates the thethreats of climate change, and the already rising costs of extreme weather events.

There's more. Enhancing water conservation and water efficiency has become a critical need in the U.S. Extracting and refining coal, oil and

natural gas, as well as using it to generate electricity, all require water — and lots of it. The more we use to produce electricity and fuels for transportation, the less we have for drinking and food production.

Using wind and solar energy to generate electricity significantly reduces water consumption and use.

Wind power alone saved 36.5 billion gallons of water in 2013, according to ACORE's report. Dubbing wind energy a "drought-resistant cash crop," farmers and ranchers are receiving consistent income from wind turbines installed on their land.

Now when you stack up and add, or multiply, all the advantages and benefits wind, solar and renewable energy afford society as compared to the predominant source of energy of the past 100-plus years – coal, oil and natural gas – it's a wonder how the elected "representatives of the people" could get away with continuing to support and subsidize fossil fuels while opposing and seeking to eliminate the comparatively little that's been done to support, subsidize and otherwise provide incentives for renewable sources of energy.

This begs the question of whom, exactly, our elected "representatives" are actually serving. And that's a question for another article, a series of articles, or indeed, an entire book.

Images courtesy of ACORE

What Would Jefferson Do?

The Historical Role of Federal Subsidies
in Shaping America's Energy Future

BY Nancy Pfund AND Ben Healey

SEPTEMBER 2011

DBL INVESTORS
DOUBLE BOTTOM LINE VENTURE CAPITAL

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Some argue that the consumer can purchase warmth or work or mobility at less cost by means of coal or oil or nuclear energy than by means of sunshine or wind or biomass. The argument concludes that this fact, in and of itself, relegates renewable energy resources to a small place in the national energy budget. The argument would be valid if energy prices were set in perfectly competitive markets. They are not. The costs of energy production have been underwritten unevenly among energy resources by the Federal Government.

— August 1981 report of the DOE
Battelle Pacific Northwest National Laboratory

Executive Summary

This paper frames the ongoing debate about the appropriate size and scope of federal subsidies to the energy sector within the rich historical context of U.S. energy transitions, in order to help illuminate how current energy subsidies compare to past government support for the sector. From land grants for timber and coal in the 1800s to tax expenditures for oil and gas in the early 20th century, from federal investment in hydroelectric power to research and development funding for nuclear energy and today's incentives for alternative energy sources, America's support for energy innovation has helped drive our country's growth for more than 200 years.

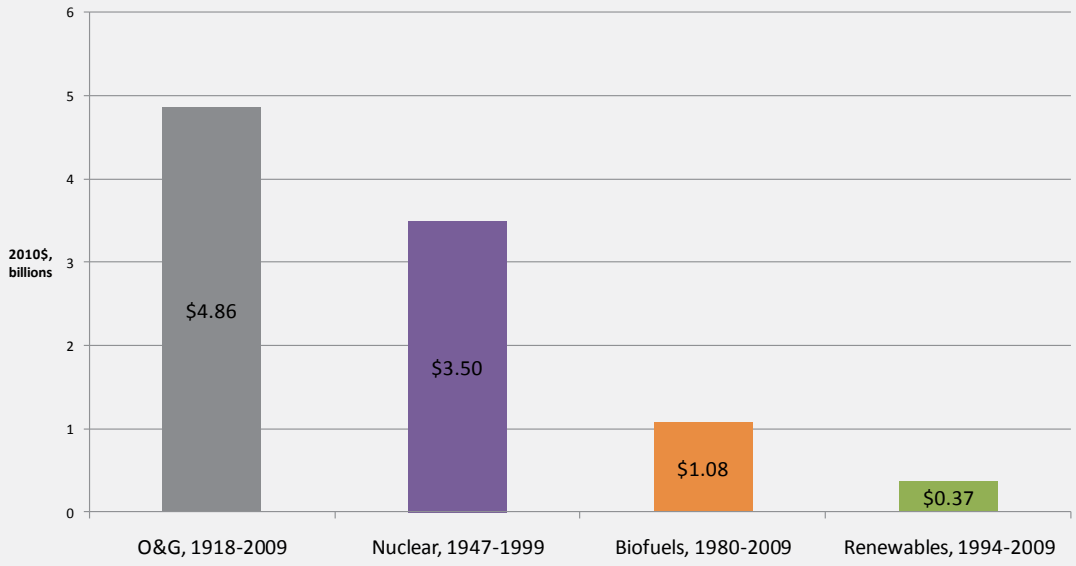
Using data culled from the academic literature, government documents, and NGO sources, in this paper we examine the extent of federal support (as well as support from the various states in pre-Civil War America) for emerging energy technologies in their early days. We then analyze discrete periods in history when the federal government enacted specific subsidies. While other scholars have suggested that the scope of earlier subsidies was quite large, we are—as far as we know—the first to quantify exactly how the current federal commitment to renewables compares to support for earlier energy transitions. Our findings suggest that current renewable energy subsidies do not constitute an over-subsidized outlier when compared to the historical norm for emerging sources of energy. For example:

- As a percentage of inflation-adjusted federal spending, nuclear subsidies accounted for more than 1% of the federal budget over their first 15 years, and oil and gas subsidies made up half a percent of the total budget, while renewables have constituted only about a tenth of a percent. That is to say, the federal commitment to O&G was five times greater than the federal commitment to renewables during the first 15 years of each subsidies' life, and it was more than 10 times greater for nuclear.

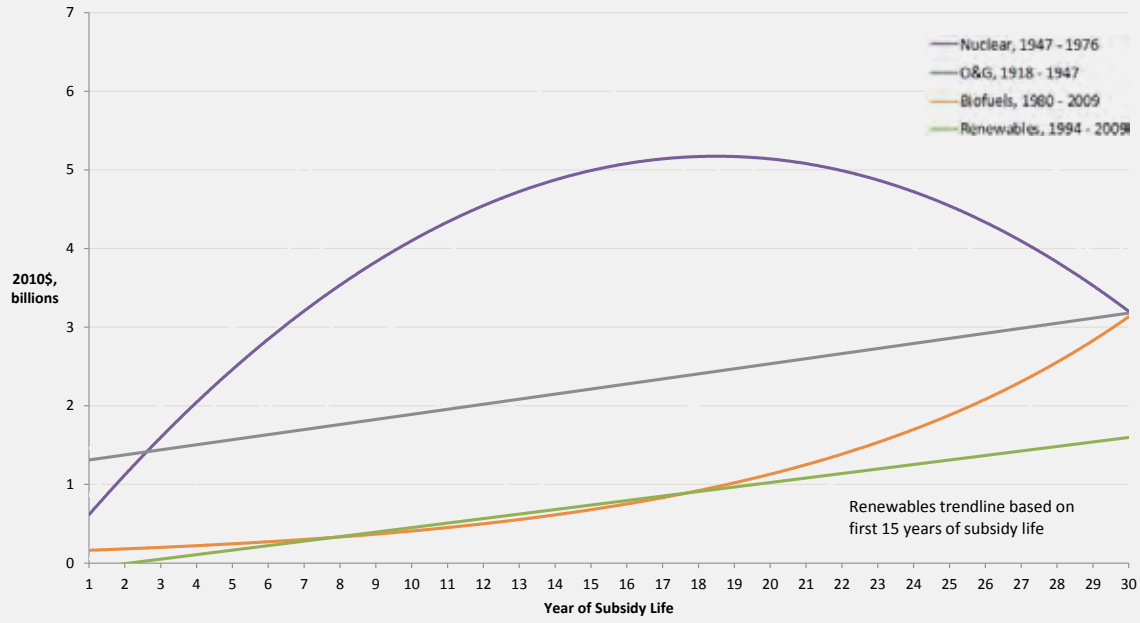
- In inflation-adjusted dollars, nuclear spending averaged $3.3 billion over the first 15 years of subsidy life, and O&G subsidies averaged $1.8 billion, while renewables averaged less than $0.4 billion.

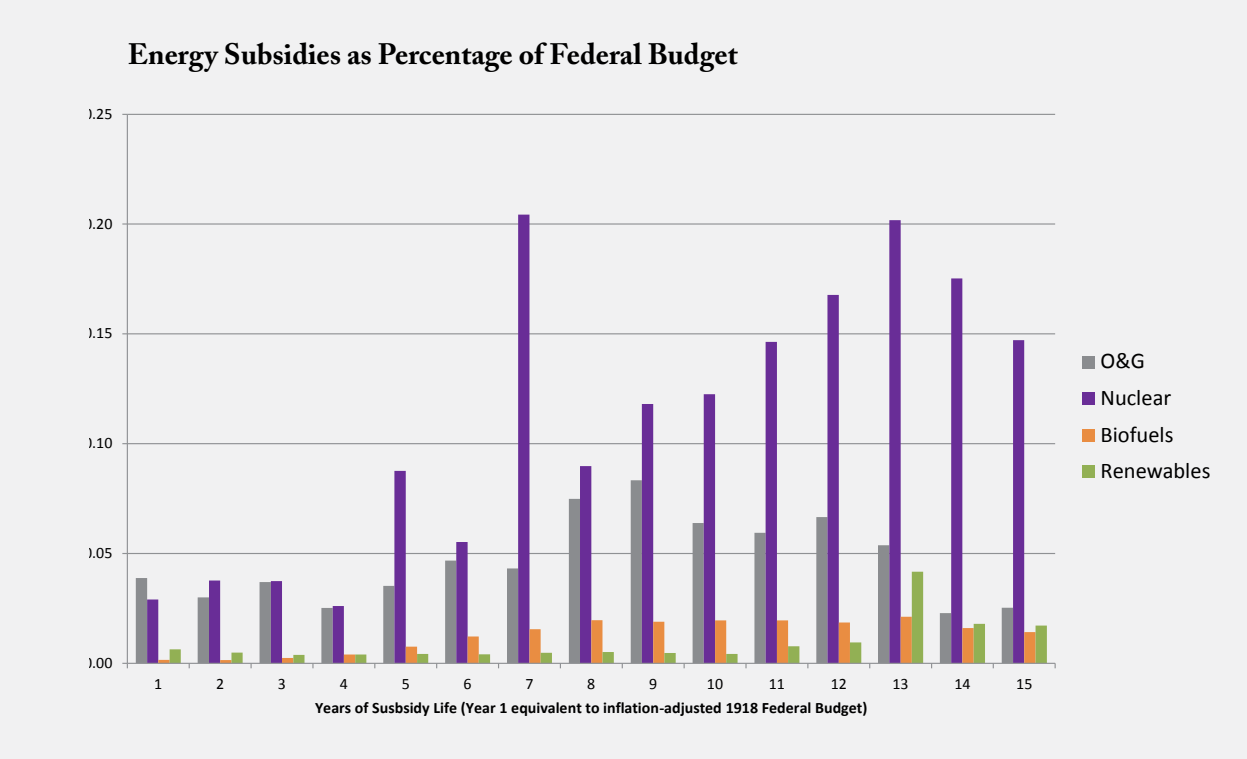
The charts below clearly demonstrate that federal incentives for early fossil fuel production and the nascent nuclear industry were much more robust than the support provided to renewables today.

Historical Average of Annual Energy Subsidies: A Century of Federal Support



Comparative Energy Subsidy Trends




Energy Subsidies as Percentage of Federal Budget
.25
.20
.15
.10
.05
.00
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Years of Susbsidy Life (Year 1 equivalent to inflation-adjusted 1918 Federal Budget)
O&G
Nuclear
Biofuels
Renewables

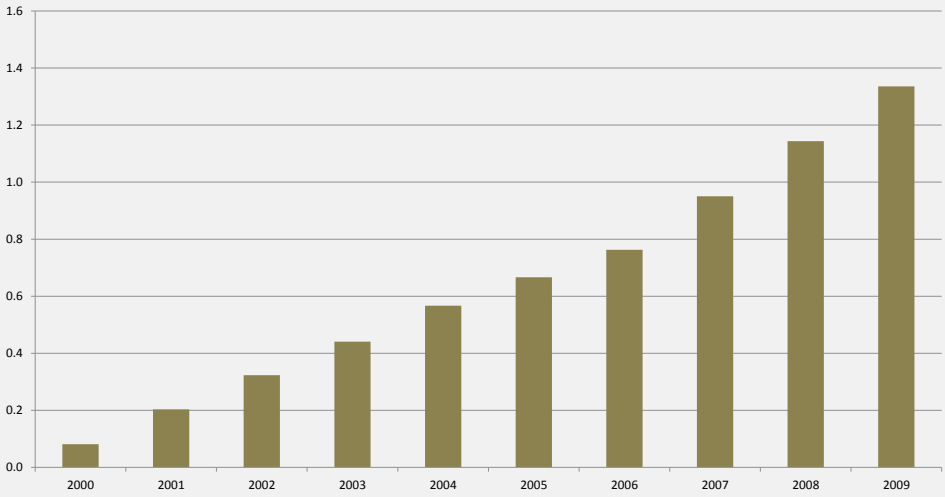
Introduction

Over the course of decades, contentious debates have raged in Washington, DC about the appropriate size and scope of federal subsidies to the energy sector, including support for both traditional fossil fuel industries and the emerging renewable energy sector. Certainly, a quick survey of existing subsidies demonstrates that critics have plenty of legitimate reasons to complain. Take the capital gains treatment of royalties on coal as an example. This subsidy allows owners of coal mining rights to reclassify income traditionally subject to the income tax as royalty payments, thereby allowing owners to pay a reduced tax rate:

In 1950 and 1951, Congress increased a number of taxes to pay for the United States' entry into the Korean War. With prevailing 1951 marginal income tax rates ranging up to a high of 91 percent and capital gains tax rates at 25 percent regardless of income, the reclassification was primarily adopted to insulate certain owners of coal mining rights from high marginal income tax rates … thus encouraging additional production. Since then, both income and capital gains tax rates for individuals have fallen, and the capital gains tax rate for individual owners currently stands at 15 percent. However, the credit is still available to members of the coal industry.[1]

This subsidy totaled well over $1.3 billion in government tax expenditures from 2000 – 2009:

Cumulative Capital Gains Treatment of Royalties on Coal, 2000–2009
(2010$, BILLIONS)



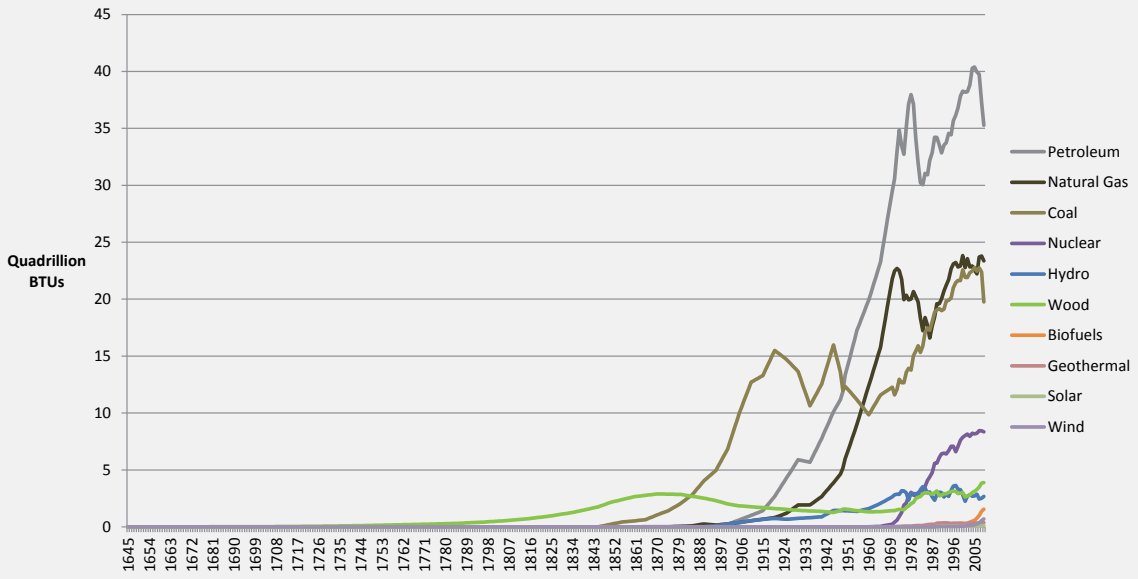
Source: Joint Committee on Taxation

1 David Sher, Environmental and Energy Study Institute, "Fossil Fuel Subsidies: A Closer Look at Tax Breaks, Special Accounting, and Societal Costs" (June 2011).

True, this Korean War-era tax break seems grossly out of place in the 21st century, but not all subsidies are created equal. Historically, policymakers have justified intervention in energy markets "1) to promote a new technology during the early developmental stages and 2) to pay the difference between the value of an activity to the private sector and its value to the public sector."[2] Thus, it is worth evaluating our current energy subsidies through a longer historical lens, so that we can better understand how current incentives compare to past government support for the energy sector.

U.S. Growth and Historical Energy Transitions

Primary U.S. Energy Consumption



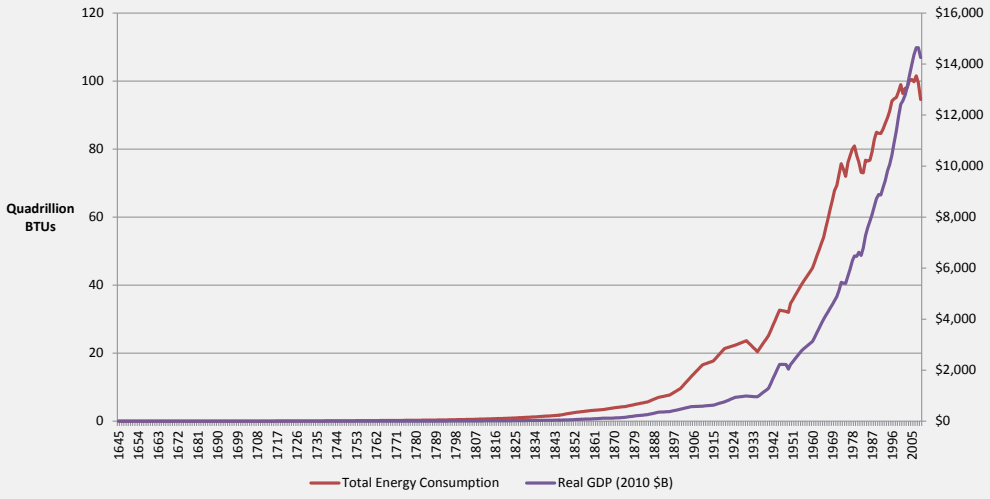
Source: Energy Information Administration

2 Mona Hymel, Arizona Legal Studies Discussion Paper No. 06-15, "Americans and Their 'Wheels': A Tax Policy for Sustainable Mobility" (February 2006).

We can read the history of the United States—our country's geographic and economic expansion—through the history of our energy production and consumption. Through war and peace, through westward expansion and our rise to economic and military superpower status, we find that energy transitions fueled it all. Wood and small hydro powered our country's early, rural days. As cities expanded, railroads crisscrossed the nation, and the Industrial Revolution took hold, coal dominated. With the invention and improvement of the internal combustion engine, oil catapulted into our preeminent fuel. Large hydro became a reality thanks to Depression-era initiatives that have continued to drive economic development programs across the country decades later, followed by nuclear power on the heels of World War II. And today, in pursuit of greater energy security, enhanced environmental quality and economic growth on a globalized playing field, renewable energy sources are transitioning from the margins to the mainstream. As the chart below starkly illuminates, our wealth and our energy usage are intimately intertwined.

Energy innovation has driven America's growth since before the 13 colonies came together to form the United States, and government support has driven that innovation for nearly as long. In this paper, we identify specific government interventions in the energy sector during moments of transition, and we attempt to quantify that support in order to compare it to current support for emerging renewable sources of energy. Although most of our quantitative analysis focuses on federal support, it is important to note that states have also contributed to the American energy narrative throughout our history, from the support of coal in the 19th century to incentives for renewable energy production 200 years later, and we will not ignore the role of the various states in the discussion that follows.

Primary U.S. Energy Consumption vs. GDP



Source: Energy Information Administration and MeasuringWorth

Overall, what we find, in contrast to much of today's headline-grabbing rhetoric, is that today's government incentives for renewable energy pale in comparison to the kind of support afforded emerging fuels during previous energy transitions.

Look back to the 1700s:

From Battelle National Lab – "The first recorded commercial coal transaction in the United States was a 32-ton shipment from the James River district in Virginia to New York in 1758."[3]

…Into the 1800s:

From Stanford's Center for International Security and Cooperation – "As a pamphleteer wrote in 1860, a year after Uncle Billy Smith struck oil at Oil Creek in Titusville, Pennsylvania, 'Rock oil emits a dainty light, the brightest and yet the cheapest in the world; a light fit for Kings and Royalists and not unsuitable for Republicans and Democrats.'"[4]

From the Renewable Energy Policy Project – "The first attempt to transport natural gas on a large scale was in Rochester, New York in 1870. A 25-mile line was constructed of hollowed pine logs. It was a failure."[5]

…Through the 1900s:

From Greenpeace – "In December, 1953, President Eisenhower inaugurated an 'Atoms for Peace' [nuclear energy] program that… would ultimately swallow the lion's share of federal dollars for energy research."[6]

3 R.J. Cole, et. al., DOE Battelle Pacific Northwest Laboratory, "An Analysis of Federal Incentives Used to Stimulate Energy Consumption" (August 1981).

4 Richard Rhodes, Stanford University Center for International Security and Cooperation, "Energy Transitions: A Curious History" (September 19, 2007). Rhodes is a Pulitzer Prize-winning journalist and historian.

5 Marshall Goldberg, Renewable Energy Policy Project, "Federal Energy Subsidies: Not All Technologies are Created Equal" (July 2000).

6 Komanoff Energy Associates, Greenpeace, "Fiscal Fission: The Economic Failure of Nuclear Power" (December 1992).

Timber and Coal in the 19th Century

Although we think of today's subsidies in terms of tax policy, government research and development initiatives, or direct spending on behalf of an industry, the 19th century had its own vehicle of public support: land. From the Preemption Act of 1841 to the Homestead Act of 1862 to the Timber and Stone Act of 1878, it was official policy of the early U.S. government to make land grants to its citizens at below-market prices in order to encourage settlement, expansion, and economic development. Rather than actual land, though, government policy took the form of distributing warrants for land ownership, which industry representatives often purchased at a discount. According to one historian:

The land, including natural resources, constituted an enormous stock of assets available for transfer. As a rough estimate of the order of magnitude, the land transfers were tantamount to an annual deficit of about 30 percent of the latter 19th century annual federal budgets. [In total,] over 13.5 million acres of timber land was alienated, amounting to four-fifths of the forest domain.7

Of course, it would be inappropriate to consider these land grants as subsidies solely to the timber industry in and of itself. If we conservatively estimate, however, that only 5% of these massive land grants subsidized the use of timber, and that only half of that amount was actually for energy purposes, still it would amount to about a 25 billion-dollar a year energy subsidy, as an equivalent percentage of today's federal budgets. This estimate does not even include indirect support for the timber industry though land grants to the railroads: "As early as the mid-nineteenth century, logging operations were highly capital intensive, requiring spur railroad lines and other equipment to handle the huge logs of the virgin forests. [8]"

A Native American Approach to Subsidies:

Indeed, the notion of awarding special control over key natural resources to those considered best positioned to develop them was not true solely of western expansionists: several Native American traditions restrict tribal access to key plants and trees used in basket-making to selected apprentices and allow only certain elders and other respected elites to actually make the baskets. One might consider this role the "oil refining" of this particular natural supply chain.[9]

7 Fred E. Foldvary, Southern Economic Association Meetings, "Ground Rent Seeking in U.S. Economic History" (November 21, 1997). Foldvary is a lecturer in economics at Santa Clara University.

8 Gary D. Libecap and Ronald N. Johnson, The Journal of Economic History Vol. 39, No. 1, "Property Rights, Nineteenth-Century Federal Timber Policy, and the Conservation Movement" (March 1979).

9 Lois Conner (Yokuts basketmaker) and Ruby Pomona (Mono Elder) presentation on June 7, 2011 at the "Trails of Fire: Signatures of Cultural and Environmental Transformations on the American and Australian Frontiers," conference at Stanford University held June 6-9, 2011.

Early support for coal did not lag far behind timber:

Each state had its own energy policy—which, taken together, created a highly fragmented and somewhat chaotic regulatory regime that encouraged the production and consumption of vast quantities of coal. Nature made coal abundant; public policy made it cheap.[10]

At the federal level, in the late 1700s, Congress enacted a protective tariff, one of a number of early pieces of economic legislation that has left an import/export tension embedded in American economic policy to this day:

Coal is extremely bulky, making it expensive to transport. In the colonial era, British merchants had transported coal to American ports free-of-charge as ballast for ships. The first federal tariff on imported coal dated from 1789 … [and until 1842] the tariff remained at least 10 percent the price of foreign coal—more than enough to give domestic producers a major cost advantage.[11]

Federal protection was critical in the coal industry's early days, but the real action was at the state level. After the discovery of anthracite in Pennsylvania, "State officials exempted anthracite from taxation, provided incentives for smelters to promote its use, and publicized its advantages within and outside the state." Even more important than the industry's exemption from taxation was the state's use of corporate charters to encourage new production:

Early American anthracite miners
Source: U. of Toledo Professor Gregory Miller's Great Americans series[14]

The Pennsylvania legislature carefully regulated the granting of corporate charters. To promote corporate mining … the legislature permitted incorporation only in coalfields in which the industry had yet to become well established, designating the territory in which they could operate and the amount of capital they could raise.[12]

What began in Pennsylvania quickly spread:

Over time, states competed ever more vigorously to promote the production and consumption of coal—perpetuating a tradition of rivalistic state mercantilism that had been a pillar of state-sponsored public works programs in the early republic. … For states that had yet to develop a coal industry, one common—and often effective—legislative stratagem was to sponsor a geological survey. In 1823, North Carolina hired a geologist to catalog the state's mineral resources; by 1837 fourteen states had followed North Carolina's lead. State geological surveys were at once scientific and economic: by inventorying the state's mineral resources, they would, or so legislatures hoped, identify rich deposits of precious metals—including coal. In Pennsylvania and Illinois, the legislature went so far as to instruct geologists to map the coalfields. … [These] published survey reports contained valuable data that substantially lowered the cost of exploration.[13]

10 Sean Patrick Adams, The Journal of Policy History Vol. 18, No. 1, "Promotion, Competition, Captivity: The Political Economy of Coal" (2006).

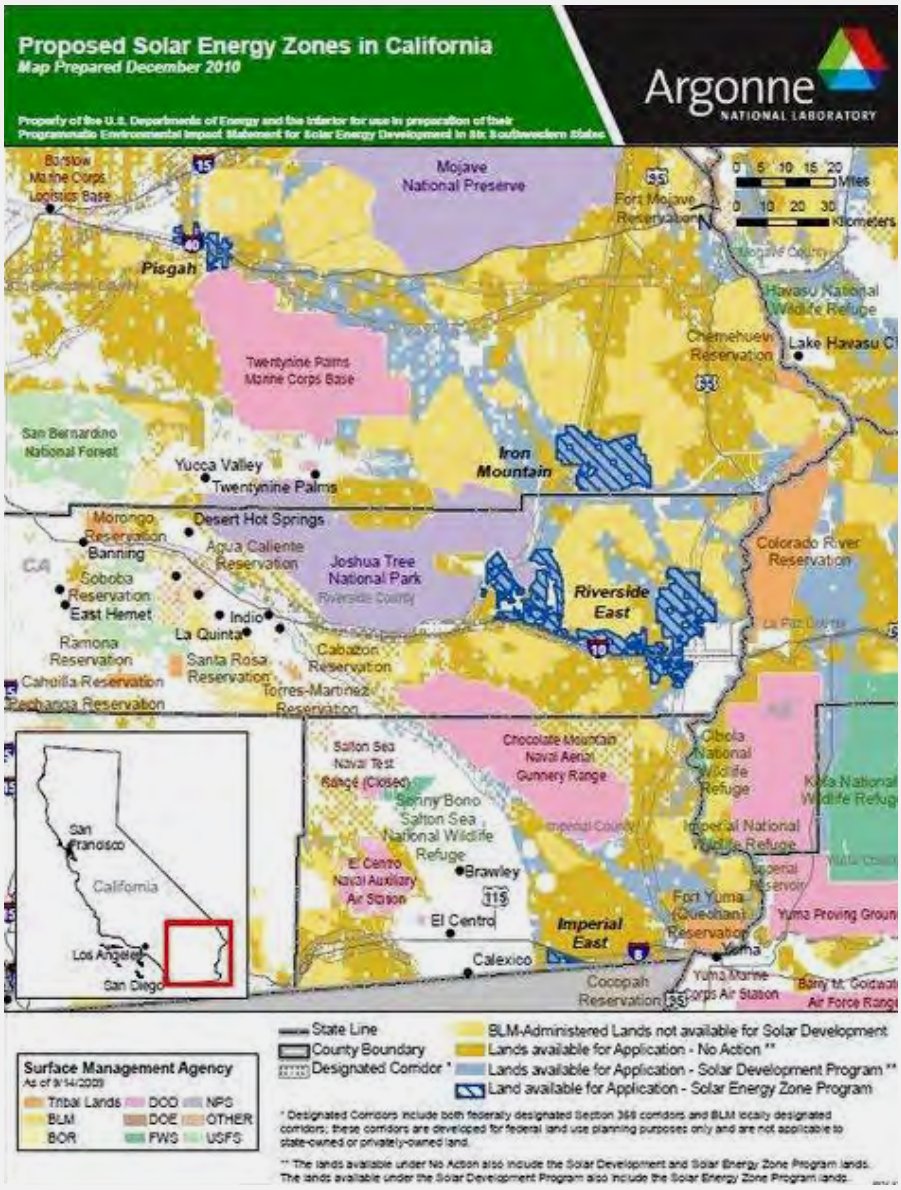
11, 12, 13 Ibid. Adams.

14 Available at http://greatamericansclass.blogspot.com/2010/03/1902-anthracite-coal-strike.html.

Government Land Surveys, from Coal to Solar

These early state-sponsored geologic surveys, intended to spur coal development, are not so different from today's attempts by the Department of the Interior to advance solar development:

The Interior Department has identified some two dozen potential sites for large-scale solar power installations on public lands in six Western states as part of an effort to encourage development of renewable energy on public lands and waters.15



15 John M. Broder, The New York Times, "Officials Designate Public Lands for Solar Projects" (Dec 16, 2010).

Early support for coal only grew as technology helped drive further demand for the fuel:

> Following the Civil War, the railroads expanded tremendously. … The trains themselves used a great amount of coal. Steam locomotives switched to coal from wood, which was starting to become less available and more costly in some areas. … [In addition,] the Bessemer process for steelmaking … made possible the large-scale, low-cost production of steel and greatly increased the demand for coal. Finally, the railroads made expansion of coal mining possible by providing the transportation network necessary for serving the expanding markets.[16]

It almost goes without saying, of course, that the transportation network created by the railroads would never have been possible without the same kind of federal land grants that so benefitted the timber industry. Any proper accounting of early government support for the coal industry must factor in these grants, which served to promote an exponential increase in coal consumption nationwide.

As the railroads grew, "The high price of coal and iron … created a furor … amounting almost to a mania, and the files of both houses [in Pennsylvania were] filled with bills for chartering new Coal and Iron Companies," according to a contemporary 1864 piece in the influential Miners' Journal. This craze was not unique to Pennsylvania, with newly discovered coal deposits driving the granting of corporate charters around the country.

Along with these charters, legislatures granted special rights to railroad companies that allowed them to vertically integrate so as to drive further coal production. In 1861, for example, "Pennsylvania granted railroads the ability to purchase the stocks and bonds of other corporations, a valuable concession they previously had been denied."[17] In 1869 the legislature made explicit its intent in the 1861 bill by clarifying the right of railroad companies to invest in coal-mining corporations.

Since the end of the Civil War / Reconstruction Era, tremendous subsidies have continued to flow to the coal industry. However, since our aim in this paper is to discuss government subsidies to the various energy sectors in their early days, we will not return to a lengthy discussion of later government support for the coal industry. Suffice it to say, domestic coal did not arrive on the scene as a mature, low-cost and competitive fuel source. Rather, government support over many years helped to turn it from a local curiosity in Schuylkill County, Pennsylvania into the dominant fuel source of its time.

16 Op. cit. Cole, et. al.

17 Op. cit. Adams.

Categorization of 20th Century Subsidies

As we turn from a qualitative account of 19th century subsidies towards a quantitative analysis of more recent federal support for the various energy sectors, it is useful to establish a framework of the different kinds of subsidies that have played a role in shaping today's energy infrastructure and markets. Management Information Services, Inc., a Washington D.C.-based economic research and management consulting firm, has provided a clear subsidy taxonomy that we lay out below:

A. Tax Policy
Tax policy includes special exemptions, allowances, deductions, credits, etc., related to the federal tax code.

B. Regulation
This category encompasses federal mandates and government-funded oversight of, or controls on, businesses employing a specified energy type. Federal regulations are an incentive in the sense that they can contribute to public confidence in, and acceptance of, facilities and devices employing a new or potentially hazardous technology. Federal regulations or mandates also can directly influence the price paid for a particular type of energy.

C. Research and Development
This type of incentive includes federal funding for research, development and demonstration programs.

D. Market Activity
This incentive includes direct federal government involvement in the marketplace.

E. Government Services
This category refers to all services traditionally and historically provided by the federal government without direct charge. Relevant examples include the oil industry and the coal industry. U.S. government policy is to provide ports and inland waterways as free public highways. In ports that handle relatively large ships, the needs of oil tankers represent the primary reason for deepening channels. They are usually the deepest draft vessels that use the port and a larger than-proportional amount of total dredging costs are allocable to them.

F. Disbursements
This category involves direct financial subsidies such as grants. An example of federal disbursements is subsidies for the construction and operating costs of oil tankers.[18]

This taxonomy is quite helpful in laying out the complete universe of subsidies that we could potentially explore. Many of these subsidies, however, are quite difficult to measure, and a lively debate exists in the NGO and academic literature about which should fully count as subsidies to the energy industry. Let's look at a few examples:

One of the key factors in bringing natural gas to the East Coast was the conversion to natural gas of the Big Inch and Little Inch oil pipelines, which had been built during World War II as means of bringing crude oil to the East Coast without fear of German submarine attack."[19]

18 Management Information Services, Inc., prepared for The Nuclear Energy Institute, "Analysis of Federal Expenditures for Energy Development" (September 2008).
19 Op. cit. Cole, et. al.

How should one value this contribution to America's natural gas network, which clearly acts as an ongoing subsidy to gas despite its original, defense-related purpose?

Sticking with natural gas, consider the development of the combustion turbine:

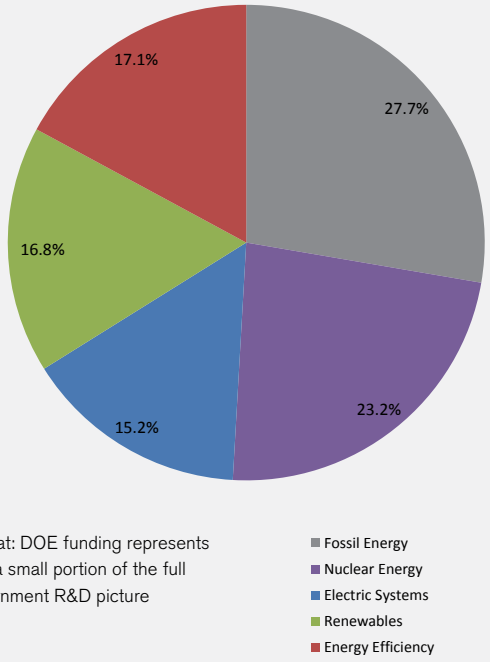
Its pedigree traces back to jet engines. For decades, utility managers found generating units based on jet technology cheap, but inefficient and unreliable. Largely through government funded R&D on combustion turbines for aircraft use, the technology improved. Reportedly, the Defense Department invested an average of $425 million per year in jet engine R&D from the mid-1970s to the mid-1980s, reaching $750 million annually in the late 1980s. In the 1990s, the independent power sector used these cheap, effective, government-enabled "aero-derivative" turbines to challenge the dominance of established utilities.[20]

Of the hundreds of millions of dollars spent by the government developing these turbines, how much—if any—should be charged to the natural gas subsidy account?

Of course, just to look at the renewable side of the equation, there is a long history of NASA research and development money supporting solar energy technologies, as well. Management Information Services estimates that from 1950 – 2006, NASA spent nearly $1 billion (in 2010$) on R&D devoted to solar. While significantly smaller than the hundreds of millions of dollars spent annually on combustion development, this early government support for solar was nonetheless critical to the technology's eventual commercialization.

According to the Congressional Research Service, "For the 63-year period from 1948 through 2010, nearly 12% [of DOE R&D spending] went to renewables, compared with 9% for efficiency, 25% for fossil, and 50% for nuclear."[21] The chart below shows the breakdown for the most recent 10-year period of our history. But since this graphic fails to account for the spillover benefits of Department of Defense or NASA R&D spending, it clearly gives us only a small portion of the full R&D picture.

DOE Energy Technology Share of Funding,
FY2001–FY2010



20 Op. cit. Goldberg.

21 Fred Sissine, CRS, "Renewable Energy R&D Funding History: A Comparison with Funding for Nuclear Energy, Fossil Energy, and Energy Efficiency R&D" (January 26, 2011).

The challenge of determining what subsidies to include is not simply about parsing historical data appropriately. Even today, a wide variety of ongoing subsidies to every sector of the energy industry might merit inclusion in our study, including many that are hot-button items. For example, a recent article in the New York Times lays out existing oil and gas loopholes that are currently under fire:

> More than $12 billion [in government savings] would have come from eliminating a domestic manufacturing tax deduction for the big oil companies, and $6 billion would have been generated by ending their deductions for taxes paid to foreign governments. Critics suggest that the [oil and gas] companies have been able to disguise what should be foreign royalty payments as taxes to reduce their tax liability.[22]

This is certainly contested terrain. The domestic manufacturing tax deduction applies to many companies—not just the major O&G players—so is it fair to count something so generally applicable against their subsidy scorecard? Perhaps, but the oil and gas industry would certainly argue not. Similarly, the fight about "dual capacity" taxpayers and foreign royalty payments is far from cut-and-dried. The current tax treatment is clearly beneficial to the oil and gas industry, but does it count as a subsidy, or is it simply an appropriate method of avoiding double taxation? This is complicated stuff, so in the following section, we do our best to lay out the boundaries of our own study, in an effort to be transparent and to demonstrate that the historical comparisons we are making are as close to "apples-to-apples" as possible.

22 Carl Hulse, The New York Times, "Senate Refuses to End Tax Breaks for Big Oil" (May 17, 2011).

Key Historical Subsidies by Sector

In researching this paper, we took a very practical approach to data collection, asking ourselves four questions:

1 Was a given subsidy actually designed to increase domestic production of a given resource (or does it do so in practice, even if that was not its original intention)?

2 Was the data related to that particular subsidy available?

3 Did the subsidy exist during the early stages of a resource's domestic production?

4 Did inclusion of that subsidy increase our ability to compare subsidy levels across resources and over time?

Let us look at the Low Income Home Energy Assistance Program (LIHEAP) as an example of a subsidy not included in our calculus.

1 No, LIHEAP is not specifically designed to increase domestic production of any given fuel resource. It is questionable as to whether or not the extra dollars that LIHEAP injects into the energy market actually increase production, or simply redistribute consumption.

2 Yes, the data on LIHEAP is available.

3 No, LIHEAP is a more recent program than some of the resources that it subsidizes (i.e. oil and gas), since it began in 1980.

4 No, LIHEAP actually diminishes our ability to make meaningful comparisons, since it potentially subsidizes multiple energy resources at differing levels. It is difficult to separate the subsidy's contribution to each source.

Having failed three out of our four necessary conditions for inclusion in this analysis, we left LIHEAP out of our subsidy calculus. Royalty relief for offshore oil leases in the Gulf of Mexico is another example: although clearly measurable and relevant to increased oil production, a subsidy created in 1995 does little to shed light on our historical understanding of early-stage oil and gas production in America. Similarly, many of the modern-day subsidies examined in excellent papers by the Environmental Law Institute, Earth Track, Friends of the Earth, and the Green Scissors Campaign, not to mention recent EIA reports on the subject, have no place in our paper, since we focus on historical subsidies that had an impact as a particular energy source emerged.

Rather than articulating all of the subsidies that we exclude from this analysis due to our need for clear and consistent boundaries, then, let us instead lay out how we actually have treated each of the major energy sources that have emerged over the last 100 years of American history:

Oil and Natural Gas:

We looked solely at the subsidies embodied in the expensing of intangible drilling costs and the excess of percentage over cost depletion allowance.

From the Congressional Research Service:

For more than half a century, federal energy tax policy focused almost exclusively on increasing domestic oil and gas reserves and production. There were no tax incentives promoting renewable energy or energy efficiency. During that period, two major tax preferences were established for oil and gas. These two provisions speed up the capital cost recovery for investments in oil and gas exploration and production. First, the expensing of intangible drilling costs (IDCs) and dry hole costs was introduced in 1916. This provision allows IDCs to be fully deducted in the first year rather than being capitalized and depreciated over time. Second, the excess of percentage over cost depletion deferral was introduced in 1926. The percentage depletion provision allows a deduction of a fixed percentage of gross receipts rather than a deduction based on the actual value of the resources extracted. Through the mid-1980s, these tax preferences given to oil and gas remained the largest energy tax provisions in terms of estimated revenue loss.[23]

And from a 1990 report of the General Accounting Office:

… The marginal effective federal corporate tax rates–i.e., the tax rates on genuinely incremental investments–for domestic petroleum production are already among the lowest for a major industry, due to the effects of existing tax incentives. These analyses estimate marginal effective rates on petroleum production investments to be about half of the statutory rate for integrated producers (i.e., producers with significant refining or retail activity). Marginal effective rates can be near zero for independent (i.e., nonintegrated) producers eligible for percentage depletion, a favorable tax treatment for depletable costs. These relatively low marginal rates already provide incentives to make petroleum production investments that have pretax returns below those of investments in other industries–i.e., relatively inefficient investments. Some petroleum production investments face negative marginal effective rates. This means that such investments are actually more profitable after taxes than before taxes because they help reduce taxes on other income.[24]

**Authors' note: in 2009, domestic production of petroleum accounted for a little more than 40% of total U.S. consumption, and domestic production of natural gas accounted for more than 90% of total consumption.*

According to one analysis considering the impact of Reagan era tax reform on the oil and gas industry, "Effective tax rates on other industries average[d] about 28 percent under pre-1986 law, compared to rates on oil investments ranging from -6 percent to 24 percent under pre-1986 law."[25] Given the high profile of these two major tax expenditures, we felt on firm ground basing our analysis of oil and gas subsidies on this pair of long-lived government incentives. As one early researcher wrote, "Our findings reveal that several public policies significantly affected investment in crude petroleum reserves. … Our empirical estmates support the position that the special federal tax provisions… have induced the petroleum industry to maintain a larger investment in proved reserves than it would have in the absence of these policies."[26]

23 Molly F. Sherlock, CRS, "Energy Tax Policy: Historical Perspectives on and Current Status of Energy Tax Expenditures" (May 2, 2011).

24 Thomas J. McCool, et. al., GAO, "Additional Petroleum Production Tax Incentives are of Questionable Merit" (July 1990).

25 Robert Lucke and Eric Toder, The Energy Journal Vol. 8 No. 4, "Assessing the U.S. Federal Tax Burden on Oil and Gas Extraction" (1987).

26 James C. Cox and Arthur W. Wright, Studies in Energy Tax Policy, "The Cost-effectiveness of Federal Tax Subsidies for Petroleum: Some Empirical Results and Their Implications" (Brannon, ed. 1975).

Take it from an even more storied source: "In 1937, President Franklin Roosevelt declared that percentage depletion was 'perhaps the most glaring loophole in our present revenue law.'" [27]

Coal:

The Green Scissors Campaign is a 15-year old effort "to make environmental and fiscal responsibility a priority in Washington," sponsored by a variety of D.C.-based public interest groups. In their 2010 report, the Green Scissors analysts make the claim, "Subsidies to the coal industry began in 1932, when the federal government first began allowing companies to deduct a portion of their income to help recover initial capital investments (the percentage depletion allowance)." [28] Of course, what they mean is that modern, income tax-based subsidies began in 1932. Those who have made it this far in this paper already know that both the federal government and the various states heavily subsidized coal in the 19th century. But since we do not have access to data quantifying the coal subsidies that go back to the fuel's true origins in the early 1800s, we have chosen not to include coal subsidies in our comparative quantitative analysis.

Nuclear:

In considering how best to quantify nuclear data, we considered multiple sources and decided to use the analysis conducted by lifelong energy analyst and consultant Marshall Goldberg, a resource planner with a broad background in resource and land use policy and impact analysis. In his work, Goldberg includes principally the costs of regulation, civilian R&D, and liability risk-shifting (the Price-Anderson Act), while also taking into account both payments from the government to industry and government receipts from industry—thus coming up with a net annual figure for every year from 1947 to 1990. Although "on-budget" expenditures for the nuclear industry have been enormous, we especially value Goldberg's analysis because he attempts a rigorous quantification of the "off-budget" value of the Price-Anderson Act of 1957, which "provided federal indemnification of utilities in the event of nuclear accidents, thus removing a substantial (and perhaps insurmountable) barrier to nuclear power plant development."[29]

Congressional testimony at the time of passage confirms the importance of Price-Anderson:

For instance, the Edison Electric Institute noted "We would…like to state unequivocally that in our opinion, no utility company or group of companies will build or operate a reactor until the risk of nuclear accidents is minimized.[30]

27 Mona Hymel, Loyola University of Chicago Law Journal Vol. 38, No. 1, "The United States' Experience with Energy-Based Tax Incentives: The Evidence Supporting Tax Incentives for Renewable Energy" (Fall 2007).

28 Autumn Hanna and Benjamin Schreiber, the Green Scissors Campaign, "Green Scissors 2010" (2010).

29 Op. cit. Komanoff Energy Associates.

30 Op. cit. Goldberg.

Hydro:

Measuring subsidies to big hydro is a beast of a task, and there is broad disagreement about what analysts should and should not include as a subsidy. Management Information Services estimates about $80 billion in historical federal subsidies to hydroelectric power, with nearly three quarters of that total coming from their "market activity" category:

> Market activity incentives for hydroelectric energy include federal construction and operation of dams and transmission facilities—estimated as the portion of the net investment in construction and operation of dams allocated to power development and the relevant transmission facilities—and the net expenditures of the power marketing administrations.[31]

On the other hand: Data on early expenditures for hydropower are incomplete. This reflects both the scarcity of archived generation and investment data on hydropower—the development of which began in the 1890s—and the complex historical context of federal hydropower development. In particular, federal hydropower facilities often formed part of larger projects with multiple goals, including flood control, river navigability, regional development, and stimulation of the local and national economies. … For instance, most of the spending on hydropower projects undertaken by the U.S. Army Corps of Engineers and the Bureau of Reclamation in the 1930s and 1940s was considered supplemental to the primary purpose of building dams for irrigation, flood control, and public water supply, among other uses. … For this reason, it is difficult to attribute a specific portion of federal investment for power generation. Nevertheless, to assist in further investigations, the figure of $1.6 billion can be given for a set of straightforward subsidies to hydropower.[32]

This $1.6 billion figure ($2.7 billion in 2010 dollars) comes from an analysis by Doug Koplow of Earth Track, a respected think tank that works to consolidate and standardize energy subsidy data and present a comprehensive view of such subsidies so that we can better evaluate them. Koplow arrives at his $1.6 billion figure by analyzing the implicit borrowing subsidies provided to the Tennessee Valley Authority, the Bonneville Power Administration, and the other Power Marketing Administrations by the federal government over an 80-year period, thanks to their ability to access capital at lower-than-market rates.[33]

However, even with a rigorous analysis such as Koplow's, hydro data remains unsatisfying. For example, consider the fact that large hydroelectric facilities are essentially wholly owned subsidiaries of the federal government: thus, they do not need to earn private sector rates of return and can price electricity more cheaply than they otherwise would. This is clearly an important subsidy, but it is also an incredibly challenging one to measure. In the end, then, since hydro does not lend itself to facile comparisons with privately owned energy resources, we decided to exclude historical hydro data from our quantitative subsidy analysis. For those who want to dig more deeply into the subject, we recommend the analyses by both Koplow and Management Information Services, since the two follow vastly different approaches to calculating federal support for hydroelectric power.

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31 Op. cit. Management Information Services.

32 Op. cit. Goldberg.

33 Douglas N. Koplow, The Alliance to Save Energy, "Federal Energy Incentives: Energy, Environmental and Fiscal Impacts" (April 1993).

Biofuels:

Often, when comparing current energy subsidies, the conversation breaks down into a "fossil fuels vs. renewables" debate, with little thought given to the diversity of energy sources contained within each of those categories. Thus, using data from the Joint Committee on Taxation, the Treasury, and annual OMB analytical reports, we have broken out federal support for biofuels from those incentives designed to support increased wind, solar, and geothermal energy production. Our comparison takes into account both the income tax credit for alcohol fuels and the excise tax exemption for alcohol fuels, including that exemption's more recent transition to a credit:

Beginning in 2005, the volumetric ethanol excise tax credit (VEETC) was introduced to replace the previously available excise tax exemption for ethanol. Since excise tax credits are deductible, replacing the excise tax exemption with an excise tax credit has additional federal revenue consequences, above and beyond payouts for the excise tax credit. Specifically, income tax receipts decrease due to the higher excise tax deduction.[34]

Some biofuels subsidy analyses have also included Department of Agriculture support for farmers that has incented the growing of corn for ethanol. As the Environmental Law Institute points out,

A substantial portion of USDA's corn production subsidy payments are received by farmers who use their corn to produce ethanol. Even though these subsidies are not directed at corn growers specifically for the purpose of producing ethanol, they represent a government expenditure that benefits energy and that supports a specific fuel (and Congress has not acted to restrict the use of these subsidies in order to prevent them from supporting corn ethanol production).[35]

Although this argument certainly has merit, the fact remains that these USDA subsidies are designed to stimulate the growing of corn, not the creation of fuel. The fact that some of this corn ends up as fuel is driven by the various alcohol tax incentives, federal blending requirements, and the price of traditional fossil fuels at any given moment in time, not by USDA grants. We have not included these USDA grants in our biofuels accounting.

Renewables:

Finally, we categorize renewables subsidies as those tax subsidies—principally, the production tax credit, as well as the investment tax credit—that incent power generation from wind, solar, and geothermal sources. Although some minor incentives became law in the late 1970s, significant federal support did not take hold until after the Energy Policy Act of 1992. Thus, we begin our accounting of renewables subsidies in 1994, when the first firms really took advantage of that 1992 law:

Section 45 of the IRS code, enacted in the Energy Policy Act of 1992, provided for a production tax credit of 1.5¢ per kWh (indexed) of electricity generated from wind and closed loop biomass systems. The tax credit has been extended and expanded

34 Op. cit. Sherlock.

35 Adenike Adeyeye, et. al., Environmental Law Institute, "Estimating U.S. Government Subsidies to Energy Sources: 2002-2008" (September 2009).

over time and currently is available for wind, closed-loop biomass, poultry waste, solar, geothermal and other renewable sources. Firms may take the credit for ten years.

Nonrefundable investment tax credits for alternative energy were initially put in place in the Energy Tax Act of 1978 (PL 95-618) at a rate of 10% for solar and geothermal property. That law provided a number of investment tax credits including a credit for residential energy conservation investments. This latter credit expired in 1982. [The Energy Policy Act of 2005] increased the investment tax credit for solar to 30% [extended through 2016 as part of the Energy Improvement and Extension Act of 2008].[36]

In closing out this section, it is worth noting that the American Recovery and Reinvestment Act of 2009 included a host of temporary clean energy subsidies (many focused on energy efficiency and research and development, although some specifically targeted towards increasing renewable energy production). These temporary provisions do not fall within the scope of this paper, but we do recommend their inclusion in future longitudinal analyses.

36 Gilbert E. Metcalf, MIT Joint Program on the Science and Policy of Global Change, "Federal Tax Policy Towards Energy" (January 2007).Z

Some Thoughts on Scope—Other Important Pieces of the Puzzle

State Level Subsidies

We do not include state level subsidies in our comparative analysis, although they are clearly important in shaping the market for both renewable and fossil fuel energy sources. Thus, in order to ensure that we were not unfairly tilting the playing field in favor of renewables by excluding state renewable portfolio standards from our analysis, we did a few quick calculations:

Lawrence Berkeley National Laboratory has conducted a number of studies to evaluate the costs of various state RPS policies. LBNL's figures suggest that the median rate increase due to the introduction of RPS policies around the country is about 0.05 cents/kWh at the retail level,[37] or about $1 billion in additional costs per year across the 50% of U.S. electricity load governed by RPS policies, given current EIA estimates of about 3,700 billion kWh/year in total electricity usage.

We also considered a study conducted by a recent graduate of the Nicholas School of the Environment at Duke University, which found that the 20-year net present value of future rate increases due to North Carolina's RPS policy is about $1.6 billion, assuming current technology and prices.[38] Starting with this figure, we then estimated North Carolina's share of our national electricity usage, again recognizing that RPS policies currently cover about 50% of our country's electricity load, and we came up with a national 20-year NPV of $22.5 billion, or a little more than a billion dollars per year.

Now, according to the Texas Comptroller of Public Accounts, the State of Texas offered about $1.1 billion in severance tax incentives to the state's oil and gas industries in 2006.[39] Even assuming that Texas is the only state providing subsidies to the fossil fuel industry (which is certainly not the case), the equivalency of this billion-dollar annual figure to the size of the RPS subsidies gave us comfort that leaving out state subsidies was not unfairly biasing our analysis in favor of renewables.

37 Cliff Chen, et. al., Renewable and Sustainable Energy Reviews Vol. 13, "Weighing the Costs and Benefits of State Renewable Portfolio Standards in the United States: A Comparative Analysis of State-Level Policy Impact Projections" (2009).

38 Ting Lei, Master's project for the Nicholas School of the Environment at Duke University, "A Cost Impact Analysis of the Renewable Energy and Energy Efficiency Portfolio Standard for Investor-Owned Utilities in North Carolina" (May 2011).

39 Susan Combs, Texas Comptroller of Public Accounts, "The Energy Report 2008" (2008).

Some Thoughts on Scope—Other Important Pieces of the Puzzle

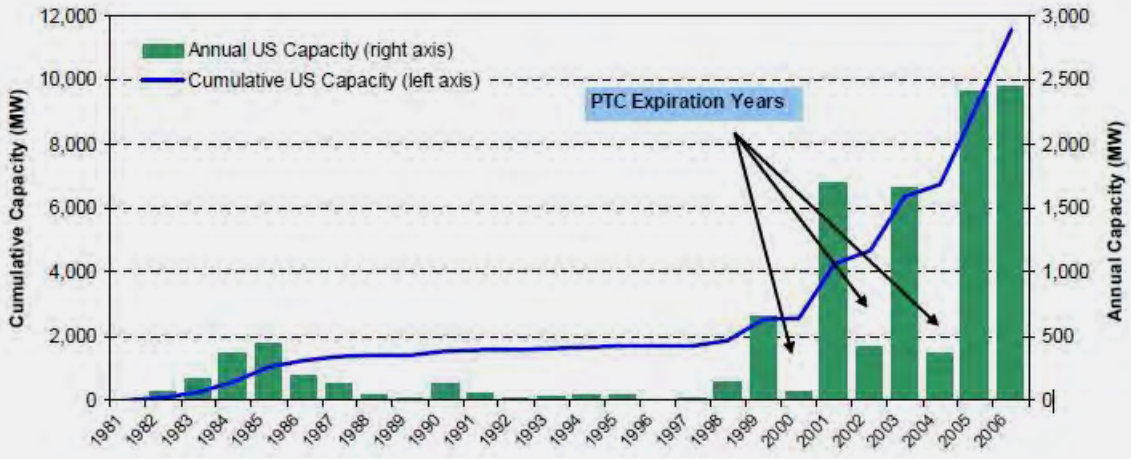
Durability

Not included in this study are the effects of the duration of various government subsidies, but to put it bluntly, policy certainty matters a great deal:

Some energy incentives, like the depletion allowance for oil and gas, are permanent in the tax code. Wind energy's primary incentive, the PTC, has been allowed to expire multiple times since its creation in 1992, and has been consistently reinstated for only one or two year terms.[40]

Due to the series of shorter-term, 1- to 2-year PTC extensions, growing demand for wind power has been compressed into tight and frenzied windows of development. This has led to boom and bust cycles in renewable energy development, under-investment in manufacturing capacity in the U.S., and variability in equipment and supply costs. Recent work at Lawrence Berkeley National Lab suggests that this boom-and-bust cycle has made the PTC less effective in stimulating low-cost wind development than might be the case if a longer term and more stable policy were established.[41]

Similarly, uncertainty regarding the near expiration of the renewable energy investment tax credit in 2008 almost single-handedly handcuffed new growth in the solar industry, before Congress renewed the credit at the last minute.



Source: Wiser Senate Testimony

40 American Wind Energy Association, "U.S. Energy Subsidies" (May 2010).

41 Ryan Wiser Testimony before the U.S. Senate Finance Committee, "Wind Power and the Production Tax Credit: An Overview of Research Results" (March 29, 2007). Wiser is a staff scientist at Lawrence Berkeley National Laboratory. He leads and conducts research in the planning, design, and evaluation of renewable energy policies, and on the costs, benefits, and market potential of renewable electricity sources.

Some Thoughts on Scope—Other Important Pieces of the Puzzle

"Minor" tax considerations

Sections of the tax code exist that one would most likely never look at to find energy subsidies, but, nonetheless, they often turn out to be critical. Not included in this study are provisions like the following:

Developers of wind farms and solar power plants have begun lobbying for legislation that would let them form master limited partnerships, a financial structure used by pipeline operators, drillers and mine operators, as well as private-equity companies such as KKR and Blackstone … that pay no corporate taxes, passing tax liability directly to investors. Eliminating the corporate tax burden increases the potential profit of master limited partnerships and makes them appealing to wealthy investors. *The tax vehicles were responsible for building much of the U.S. oil and gas pipeline networks.*[42] [italics added]

One might think that what's good for the goose should be good for the gander in terms of energy subsidies. Our research has revealed, however, that traditional fossil fuel sectors benefit from a host of older policies that the government has never extended to newer renewable forms of power generation, such as the master limited partnership provision cited here.

Defense Spending: Billions are so… civilian

Earlier in this paper, we briefly touched on the Department of Defense and NASA R&D spending that has benefited different energy technologies. But because so much of our current energy subsidy debate centers on the question of "energy security," we felt that it was worth finding out if someone has attempted to quantify how much of American defense spending—outside of R&D money—subsidizes our energy consumption (even if we do not include those numbers in our own comparative analysis):

An innovative approach comes from Roger Stern, an economic geographer at Princeton University who published a peer-reviewed study on the cost of keeping aircraft carriers in the Persian Gulf from 1976 to 2007. Because carriers patrol the gulf for the explicit mission of securing oil shipments, Stern was on solid ground in attributing that cost to oil. He had found an excellent metric. He combed through the Defense Department's data ... and came up with a total, over three decades, of $7.3 trillion. Yes, trillion.[43]

42 Bloomberg New Energy Finance, "Wind Power Wants U.S. Tax Advantage Used by Oil Companies" (July 19, 2011).

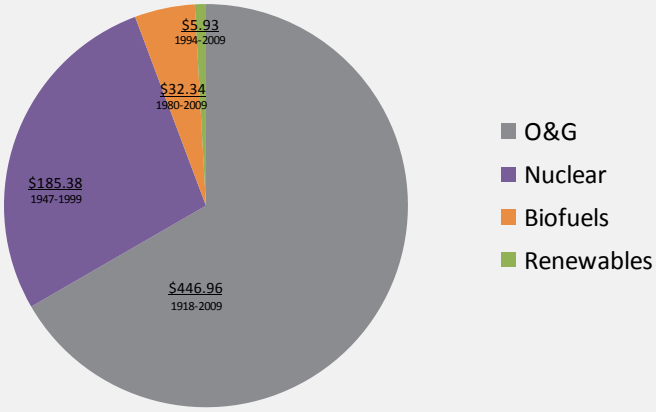
43 Peter Maas, Foreign Policy, "The Ministry of Oil Defense" (August 5, 2010).

Findings and Analysis

Finally, we come to the heart of this effort—our quantitative analysis of historical federal subsidies to the energy sector.[44] Let's start with an overview of cumulative subsidies:

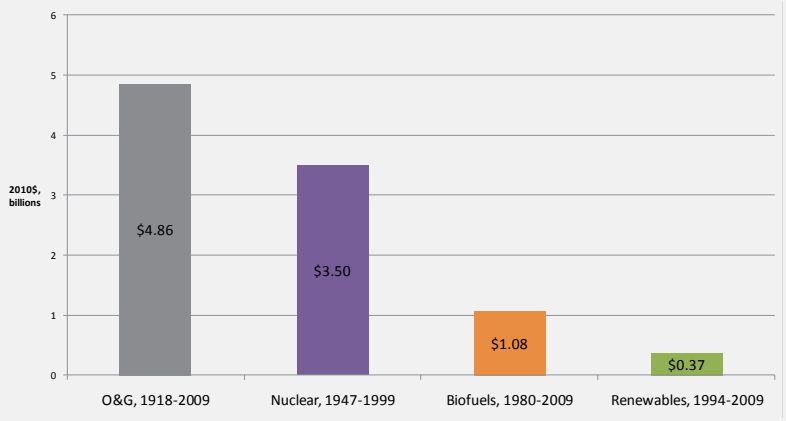
Cumulative Historical Federal Subsidies

2010$, BILLIONS



The chart above is illuminating in demonstrating the historical magnitude of oil and gas and nuclear subsidies, but it does little to facilitate useful longitudinal comparisons. Thus, we turn to the chart below, which shows the average annual subsidies to each sector over their lifetimes.

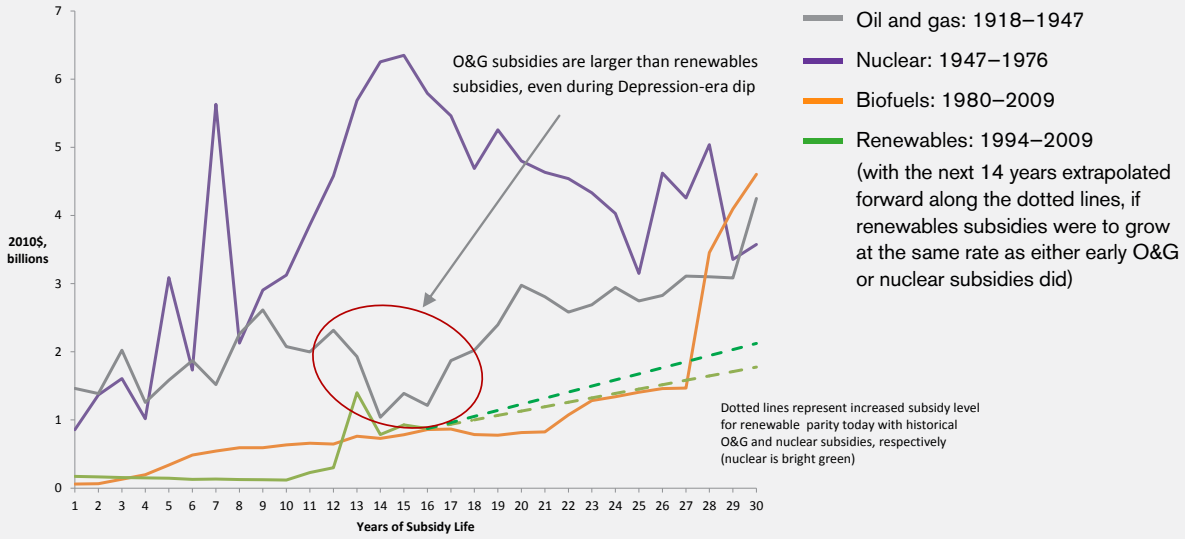
Historical Average of Annual Energy Subsidies: A Century of Federal Support



44 See Appendix for all data sourcing for this section.

Of course, what we are really trying to understand in this paper are the subsidy levels to the various energy sectors during the early days of those subsidies, as new fuel sources have emerged. The chart below tracks the actual dollar subsidies to each sector during the first 30 years of those subsidies' existence:

Comparison of Early Federal Subsidies to Energy Sectors



Looking at the jagged changes in year-over-year subsidy levels displayed in the chart above, it is probably worth noting here that most of the subsidies analyzed in this paper do not take the form of a specific legislative appropriation, which one might expect would be smoother over time. Instead, tax expenditure subsidies, for example, rise and fall according to how effectively the private sector takes advantage of them in a given year. Similarly, an off-budget subsidy such as the risk-shifting embodied in the Price-Anderson Act corresponds to the number of new nuclear plants coming online in any given year.

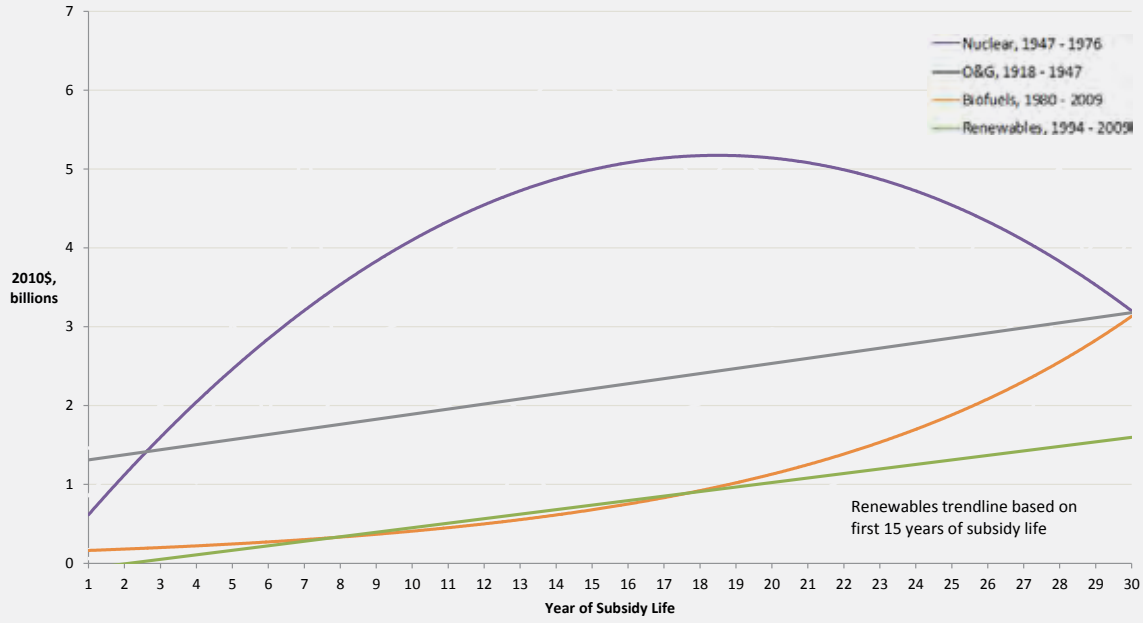
Some key points jump out from the chart above:

- Early subsidies to the nuclear industry dwarf all others;
- Biofuels subsidies rose linearly for most of their lifetime but jumped enormously due to policy changes in the mid-2000s;
- Renewable subsidies trail all others by a significant margin, with the lone exception being the 2006 jump associated with the temporary reauthorization of the production tax credit.

  However, even that high-water mark barely equaled the lowest subsidy years during the early days of oil and gas subsidies (which occurred due to falling production during the Depression).

The yearly ups and downs of the chart on the previous page make it somewhat hard to read. Below is a version of the same data, smoothed out via 30-year trend lines. Here, the point jumps out even more starkly: renewable subsidies constitute only a small percentage of the subsidies received by both the oil and gas and the nuclear industries in their early days, in inflation-adjusted terms.

Comparative Energy Subsidy Trends



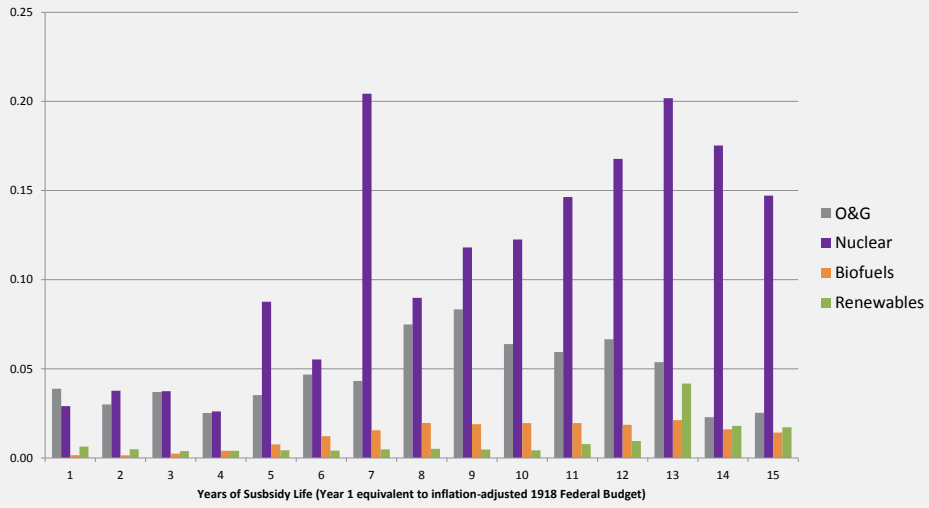
Now, on the following page is a chart that requires some explanation. If the federal budget is a reflection of spending priorities, then it would be useful to see what percentage of the federal budget various energy subsidies constituted during their early days. However, it would not be fair to compare oil and gas subsidies in 1918 to renewable subsidies in 1994 as a percentage of the budget, since the federal budget has grown so much larger due to new spending on everything from defense to agriculture to Medicaid.

What we've done, then, is taken the 1918—1932 federal budgets (which represent the first 15 years of federal oil and gas subsidies) and brought them forward in time to overlap with the introduction of subsidies to the other energy sectors. That is to say, when you look at the chart on the following page, you're looking at inflation-adjusted budgets for the years 1918—1932, absent any other increases in federal spending. Thus, you can actually get an apples-to-apples comparison of how the subsidies stack up with one another in terms of federal support.[45]

45 For example, the first tax expenditures for oil and gas occurred in 1918. We took the 1918 federal budget (year 1 for oil), and adjusted it for inflation to 1947 (year 1 for nuclear), to 1980 (year 1 for biofuels), and to 1994 (year 1 for renewables). We then did the same for each of the 1919-1932 federal budgets.

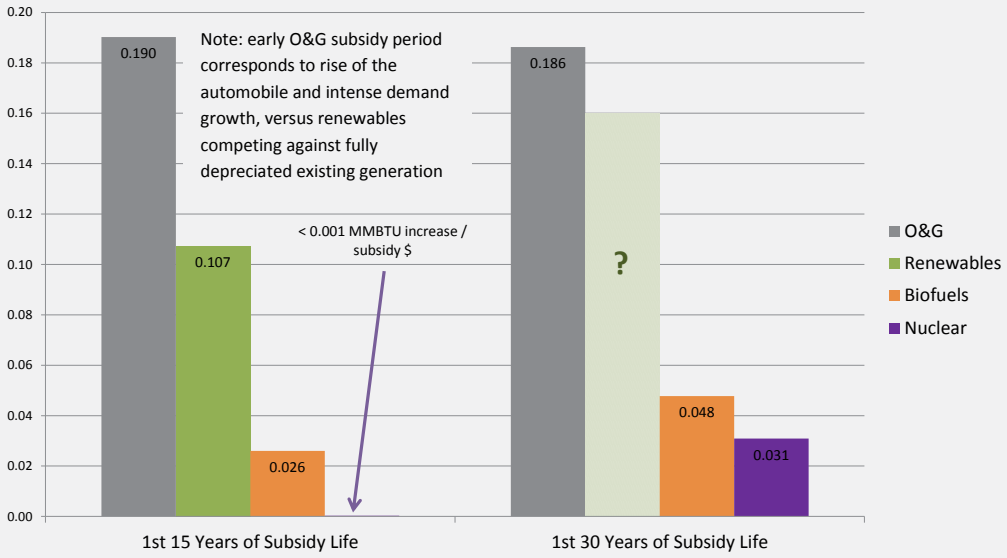
Once again, federal support for the nuclear industry overwhelms the other subsidies. Still, it is just as striking to compare the levels of support received by the oil and gas and renewables sectors. Oil and gas support never falls below a level at least 25% higher than renewables, and in the most extreme years, that support is nearly 10 times as great. This is a striking divergence in early federal incentives.

Energy Subsidies as Percentage of Federal Budget



Now, let us turn to the chart below: it examines the year-over-year increase in MMBTUs from a given energy source per subsidy dollar. It demonstrates that when seen from an incremental perspective, oil and gas production seems to outperform renewable production on an MMBTU / $ basis during the industry's early days.

Increase in MMBTUs Produced / $ in Subsidy



Nonetheless, it is worth co nsidering why this may have been the case: with oil and gas, we are analyzing a period in time (the 1920s) when the rise of the automobile was driving intense demand for oil, a fuel source with no substitute for that purpose. Producers were scrambling to keep up with skyrocketing demand, and it is unclear how much incremental supply the subsidies really incented. Looking at renewables, on the other hand, we are analyzing a set of emerging technologies competing in a commodity business (the provision of electrons) against fully depreciated coal, nuclear, and hydro facilities—all of which had also been subsidized, of course—on a grid not usually designed to support new entrants.

Keeping that perspective in mind, then, the fact that renewables have performed even half as well as oil and gas on an MMBTU / $ basis should perhaps surprise and impress us. And with renewable energy technologies improving at a rapid rate, we certainly cannot predict what a 30-year comparison graphic might eventually look like.

Discussion–

Subsidizing Apple Pie: Are the Slices Getting Smaller?

The quantitative analyses presented in the previous section, along with the qualitative discussion of 19th century energy subsidies, demonstrate that not only are incentives a tried and true American approach to driving energy innovation, but also that current subsidies for renewable technologies make up a much smaller federal commitment than was made during previous transitions. Looking at the history of American energy subsidies, a strong case can be made that in order to drive the next generation of energy technology, the federal government needs to continue its support for renewables, in line with our historical commitments to innovation:

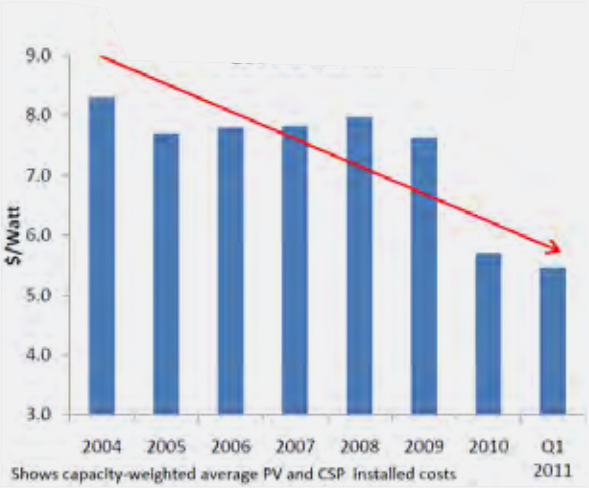
> The energy industry's entrenched infrastructure is nearly impossible to compete with absent federal tax incentives. Such incentives were instrumental in overcoming the risk factor and establishing the current petroleum industry, and they are as necessary now for the alternative fuel businesses as they were 100 years ago to overcome high initial start-up costs, minimize the risk associated with new industries, and signal to taxpayers support for these industries.[46]

Still, there is a chorus of voices in our current debate making the opposite point, as suggested in a recent USA Today opinion piece on electric vehicles (which could just as well apply to any other emerging energy technology):

> The problem with electric vehicles can be summed up with one word: subsidies. Subsidies are prima facie evidence that consumers would not buy the product at its market price. Subsidies distort markets, compromising economic growth, and are simply wealth transfers.[47]

This argument is intuitively appealing, no doubt. And for mature industries, it makes economic sense (without going into the issue of externalities and the potential need to price in environmental, social, or other consequences of a market transaction, which is a whole other question). But sticking to the purely economic perspective, consider the following recently published graphic:

Solar Average Installed Cost per Watt
2004 TO PRESENT



46 Op. cit. Hymel (2007).

47 Kenneth P. Green, USA Today, "Opposing view on energy: Subsidies? Just say no" (December 19, 2010).

As discussed earlier in this paper, combustion turbines were once uneconomic, and government support made them mainstream. That kind of innovation was surely a subsidy to the natural gas industry, but we can also agree that America as a whole is better off having access to the resulting technology. Why should current renewable technologies face different standards? Perhaps if they were unable to achieve technological and pricing breakthroughs, there would come a time when we should abandon support for them, but as the graphic on the previous page makes clear—stick with solar, and the price will continue to come down. We could chart the same price decline with wind technology, and who knows what will be next? To put the case succinctly:

Some argue that incentives should be adjusted according to the maturity of the technology …. The idea is that increased use of the technology enhances technological change–with the most potential for technological improvement occurring in new technologies. This perspective may suggest that mature technologies such as those for fossil fuels should be subsidized less than those for renewable energy sources.[48]

48 Maura Allaire and Stephen Brown, Resources for the Future, "Eliminating Subsidies for Fossil Fuel Production: Implications for U.S. Oil and Natural Gas Markets" (December 2009). Allaire is currently a PhD candidate at the University of North Carolina at Chapel Hill. Brown is the Director of the Center for Business and Economic Research at the University of Nevada, Las Vegas.

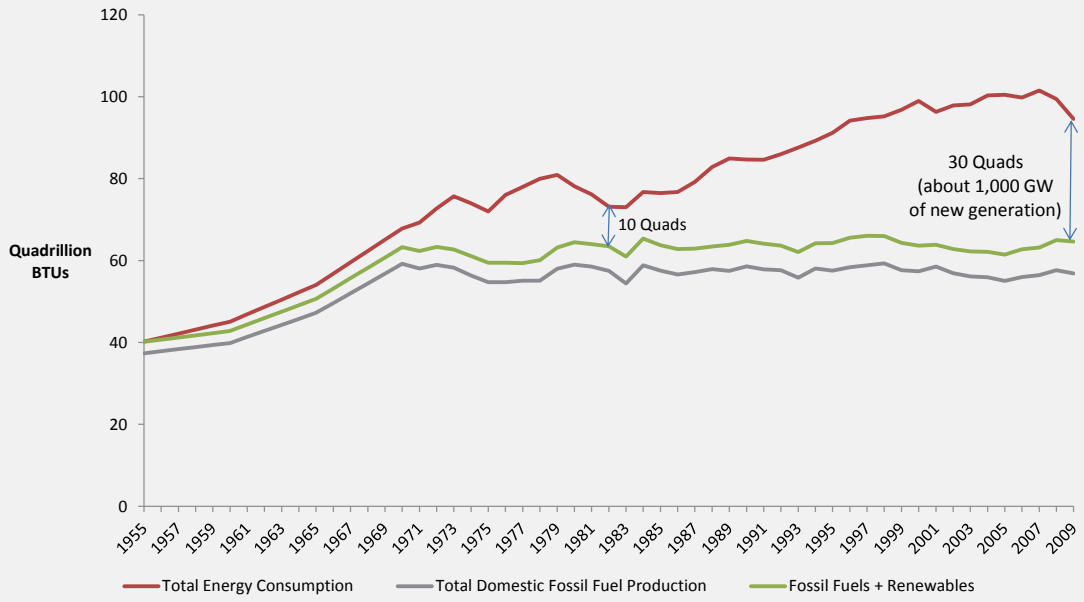
Conclusion–

In Energy We Trust

In closing, we present the two images below, the first a 1962 *Life* magazine advertisement from Humble Oil (now Exxon Mobil) and the second a graphical representation of America's current dependence on foreign sources of energy.

Source: Koplow presentation[49]

U.S. Energy Consumption vs. Production



Source: Energy Information Administration

49 Douglas N. Koplow, OECD Expert Workshop on Estimating Support to Fossil Fuels, "Quantifying Support to Energy – Why is It Needed?" (November 2010).

Together, these two images demonstrate the fact—more clearly than we ever could in words—that America's energy needs and priorities have changed over time, and that they will continue to evolve going forward, driven by economics, environmental concerns, and security issues. Throughout our history, energy incentives have helped drive critical innovation, speed U.S. economic transitions, and helped shape our national character. Today, as we seek to move towards a more independent and clean energy future, the truth is that renewables—from a historical perspective—are if anything under-subsidized. This weak support is inconsistent with our nation's own historical energy narrative, which suggests:

Today's market for cheap power results in part from substantial investment by the federal government in innovative technology.

It takes a substantial amount of money, invested over several years, to bring an electricity generation technology to maturity.

Although energy subsidies can and do serve many policy purposes, the most basic relate to furthering the development and commercialization of technologies deemed to be in the public interest.[50]

We titled this paper, "What Would Jefferson Do?" We believe that the answer to that question is now clear. He would do what our country has always done—support emerging energy technologies—to drive innovation, create jobs, protect our environment, enhance our national security in a time of rapid change, and to further a distinctly American way of life in which resources once thought to be endless are replaced by ones that actually are.

50 Op. cit. Goldberg.

Appendix:

Data Sources

Consolidated data behind the charts in the "Key Findings" section are all on file with the authors and available upon request. A list of original data sources follows below:

- Energy Information Administration: Annual Energy Review 2009

- Energy Information Administration: Federal Financial Interventions and Subsidies in Energy Markets 2007

- Marshall Goldberg: "Federal Energy Subsidies: Not All Technologies are Created Equal" (July 2000).

- Doug Koplow: "Federal Energy Incentives: Energy, Environmental and Fiscal Impacts" (April 1993).

- Mona Hymel: "Americans and Their 'Wheels': A Tax Policy for Sustainable Mobility" (February 2006).

- The Joint Committee on Taxation: Background Information on Tax Expenditure Analysis and Historical Survey of Tax Expenditure Estimates (1980 – 2010).

- Department of Treasury: President's Budget (1980 – 2010).

- Office of Management and Budget, Analytical Perspectives (1996 – 2010).

WILDLIFE

APEX CLEAN ENERGY

WIND ENERGY AND WILDLIFE

Wind energy is one of the most environmentally-friendly forms of electrical generation on the planet. That is because wind energy emits no air or water pollution, requires no mining or drilling for fuel, uses virtually no water, and creates no hazardous or radioactive waste. Clean, renewable wind energy also displaces harmful emissions from fossil fuel power plants and offsets carbon emissions, making it a safer generation option for people, wildlife, and natural ecosystems.

National Wildlife Organizations Support Wind Energy

Properly sited wind energy projects protect birds and wildlife by producing no dangerous pollutants or carbon emissions. According to the Audubon Society's website:

"Audubon strongly supports properly sited wind power as a renewable energy source that helps reduce the threat posed to birds and people by climate change. However, we also advocate that wind power facilities should be planned, sited, and operated in ways that minimize harm to birds and other wildlife..."

To ensure that our projects are responsibly sited for wildlife, Apex conducts environmental impact studies for every project. We coordinate with federal and state wildlife agencies to make sure that our projects are sited in areas where impacts to birds or bats are minimized and appropriately mitigated if necessary.

Source: North American Bird Conservation Initiative, U.S. Committee. 2014. The State of the Birds 2014 Report. U.S. Department of Interior, Washington, D.C. p 11.

In 2012, the National Wildlife Federation, ConservAmerica, and 116 other sportsmen, business, and conservation groups signed a letter asking Congress to support renewable energy projects around the country.

While birds do occasionally collide with turbine blades, modern wind farms are far less harmful to birds than buildings, communication towers, power lines, and vehicles. In fact, turbines account for only a small fraction, about .0003%, of all human-related bird deaths.

Wind Energy Has No Known Impact on Deer Population or Hunting

Just as the deer population adapts to construction of new homes, buildings, and other new sights and sounds near their habitats, deer also become accustomed to wind farms. It is not uncommon to find deer and other wildlife feeding or resting near the bases of turbines. Cattle, horses, goats and other livestock are also 100% compatible with wind energy technology.

Wind Energy Reduces Air Pollution

The amount of electricity produced by wind energy during 2016 alone displaced approximately 393 million pounds of sulfur dioxide (SO_2) and 243 million poundsof nitrogen oxides (NO_x), dangerous particulate air pollutants that are associated with conventional electric generation.* In addition, a typical new wind turbine will avoid nearly 2.8 million pounds of CO_2 annually, the equivalent of over 900 cars' worth of carbon emissions. This carbon savings helps birds and wildlife by minimizing the worst impacts of climate change, which according to scientists, could threaten between a quarter and half of all bird species.

* American Wind Energy Association

Bloomberg | Bloomberg.com

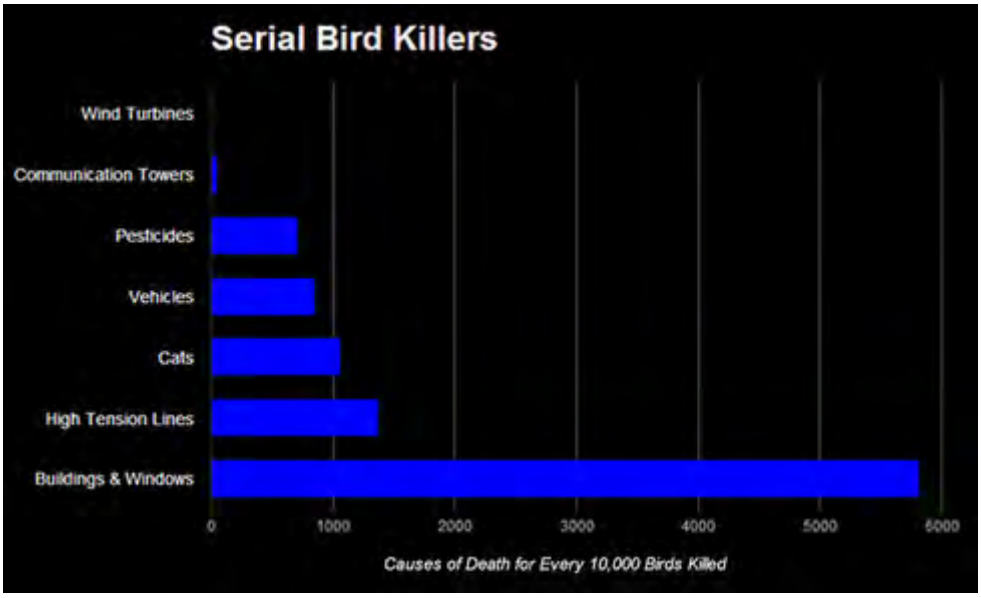
World's Top Serial Bird Killers Put Infamous Windmills to Shame

By: Tom Randall
April 21, 2014

Pity the birds.

As if cats weren't bad enough, humans have invented all sorts of torture devices for our winged friends. We've paved over their nesting sites to make room for Olive Gardens and have broken up their skyscapes with glass buildings and radio towers.

Then came the most infamous bird killer of all: the wind turbine. As you can see in the chart below, these sky blenders top the list.



Source: U.S. Fish & Wildlife Service and Vestas Wind Systems

Just kidding. Windmills aren't the biggest serial killer, but are instead the smallest threat to birds worthy of mention, on par with airplanes. Turbines are responsible for as little as one percent of the deaths caused by the next smallest killer, communications towers.

You would hardly know this by reading Twitter or scanning the comments on any news article about wind power. Here's a sampling from the gaggle of bird commenters on the story I wrote a few weeks ago about broken records in U.S. wind power:

"I assume a record number of bats and birds will be killed again."

"Wind is OK for some areas. A lot of birds will get wiped out though. Then we will see what happens."

"How many bats and birds did they slaughter this year?"

"Mass murdering devices"

The estimates above are used in promotional videos by Vestas Wind Systems, the world's biggest turbine maker. However, they originally came from a study by the U.S. Forest Serviceand are similar to numbers used by the U.S. Fish and Wildlife Service and the Wildlife Society -- earnest defenders of birds and bats.

No matter whose estimates you use, deaths by turbine don't compare to cats, cars, power lines or buildings. It's *almost* as if there's been a concerted effort to make people think wind turbines are more menacing than they actually are.

This perception can delay project permitting. An expansion of the world's largest offshore wind farm was r ecently scrapped after the U.K. would have required a three-year bird study. Only recently did the U.S. Interior Department loosen restrictions on wind farms, which according to the Wildlife

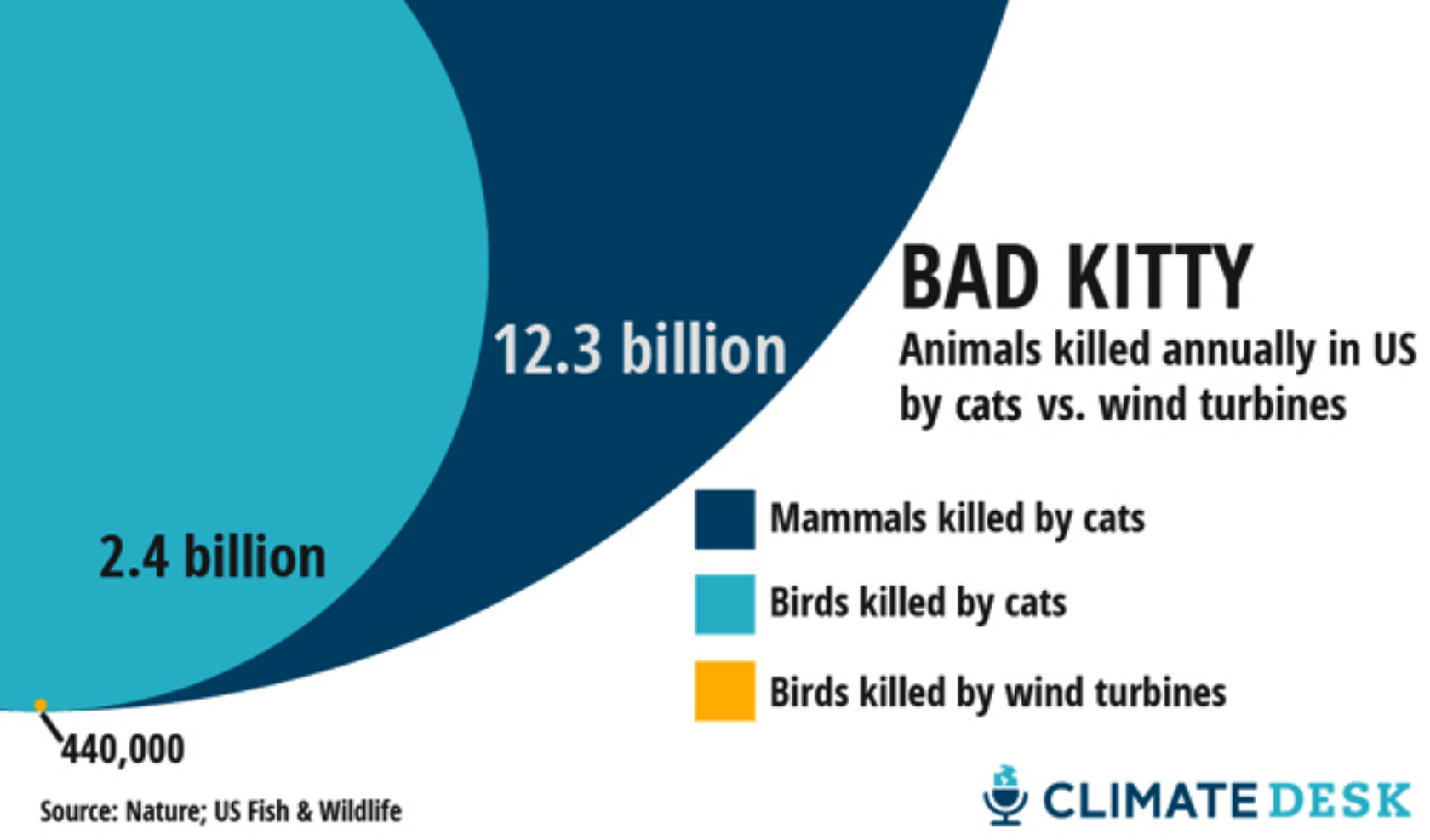
Society kill dozens of federally protected eagles and about 573,000 birds a year. Other manmade killers take out almost a billion.

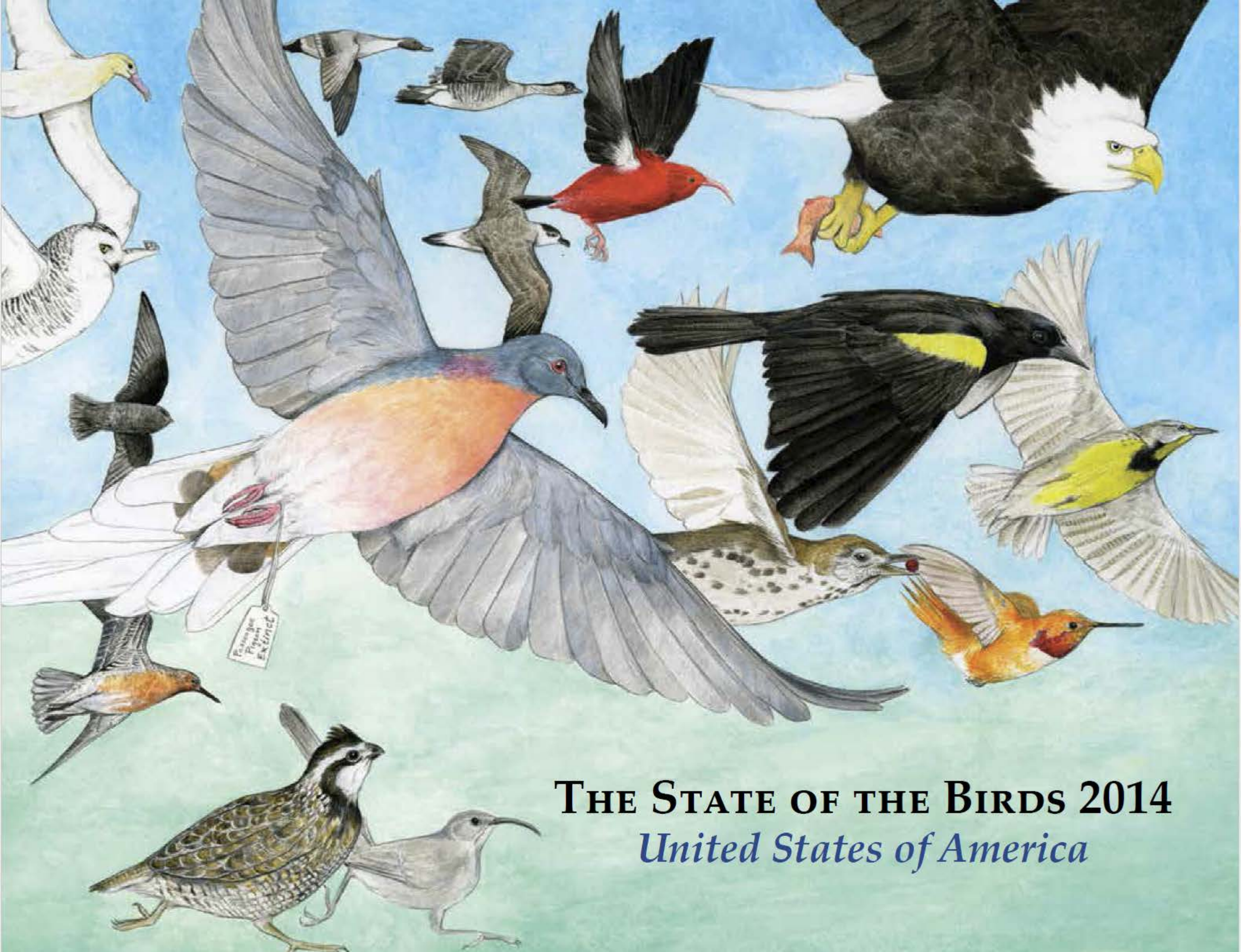
Be warned: bird deaths from wind turbines are likely to increase as wind power continues tobreak new records. Also, turbines keep getting bigger, and as you might expect, a massive bird of prey like the Bald Eagle is more likely to get into a tangle with a 700-foot-tall turbine than a housecat. Bald Eagles, for goodness sake!

It's nice for wind-farm planners to take migration patterns and endangered habitats into account. But even if wind turbines were to double in size and provide 100 percent of our energy needs (both of which defy the laws of physics as we currently understand them), they still wouldn't compare to the modern scourges of high-tension power lines or buildings with glass windows. Not even close.

The alternative to renewable energy sources like wind and solar is to burn ever more fossil fuels. Animals are threatened by those, too, including North America's most common hairless mammal: the human. Roughly 20,000 of these moderately-intelligent animals die prematurely each year from air pollution from coal and oil, according to a study ordered by Congress.

Pity the humans.


12.3 billion
2.4 billion
440,000
BAD KITTY
Animals killed annually in US by cats vs. wind turbines
Mammals killed by cats
Birds killed by cats
Birds killed by wind turbines
Source: Nature; US Fish & Wildlife
CLIMATE DESK



The State of the Birds 2014

United States of America

The State of the Birds 2014 at a Glance

ONE HUNDRED YEARS after the extinction of the Passenger Pigeon, the nation's top bird scientists from conservation groups and agencies have come together again to publish the fifth State of the Birds report.

AMERICA'S BIRD HABITATS: CONTINENTAL LANDS AND INLAND WATERS 4

Where conservation investments have been made in healthy habitats and cleaner water, birds are doing well. Due to conservation action, many wetland birds are showing strong population gains, and grassland bird populations are showing signs of improvement. Bird populations in eastern and western forests and aridlands are all in decline, reflecting the urgent need for conservation in these habitats.

AMERICA'S BIRD HABITATS: OCEANS, COASTS, AND ISLANDS 6

Coastal birds, shorebirds, and island birds are squeezed into shrinking strips of habitat impacted by development and invasive species. Some seabird populations are recovering from prior declines, though threats remain from fishing operations, offshore energy development, and climate change. Some U.S. fishing fleets are demonstrating bird-friendly fishing practices that could be a model for other countries.

PREVENTING EXTINCTIONS 8

There are 230 species on the State of the Birds Watch List of birds that are presently endangered or at risk of becoming endangered without significant conservation action. Watch List species occur in all habitats, with the highest proportion on Hawai'i. Proactive, partner-driven conservation is the best way to recover currently endangered birds and keep other species off the Endangered Species List.

PRESERVING ABUNDANCE 10

Keeping common birds common is as important as rescuing rare species. Massive population losses are occurring across several groups of common species, such as aerial insectivores, rural birds, and birds that visit from the North. While habitat conservation is most important, there are several additional sources of direct human-caused bird mortalities that could be reduced to benefit bird populations.

LESSONS OF THE PASSENGER PIGEON 12

As the Passenger Pigeon vanished, America was inspired to create the best conservation and adaptive wildlife management system the world has ever seen. Now that system needs reinvestments to take on the challenges of a new century. Unlike 100 years ago, we are now building on prior conservation successes. Today we know conservation works, and we have the science, technology, and knowledge to prevent extinctions.

OUR APPROACH 14

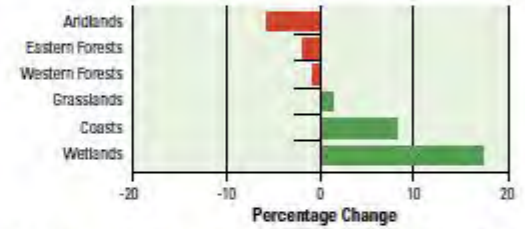
The State of the Birds habitat indicators are based on extensive reviews of population trend data from long-term monitoring. The Watch List and Common Birds in Steep Decline are derived from a complete conservation assessment of all U.S. bird species.

Photos, left to right: Greater Sage-Grouse, Snowy Owl, and Golden-winged Warbler by Gerrit Vyn; 'I'iwi by Jack Jeffrey; Northern Pintail by Peter Orr LRPS, www.peterorrphotography.com; Purple Gallinule by Vivek Tiwari, www.flickr.com/spiderhunters

The 2014 State of the Birds assesses the health of our nation's bird populations through a set of habitat indicators, a Watch List of species most vulnerable to extinction, and a list of the Common Birds in Steep Decline.

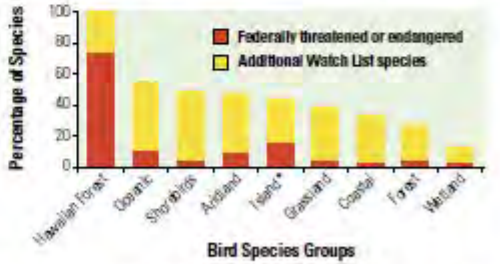
Habitat indicators are based on the population changes of obligate bird species—those birds restricted to a single habitat—where long-term monitoring data is available. This year's indicators repeat the method from the original 2009 State of the Birds.

HABITAT INDICATOR CHANGE SINCE 2009 STATE OF THE BIRDS REPORT



Aridland birds continue to show the steepest declines, while coastal and wetland bird populations continue to increase.

2014 STATE OF THE BIRDS WATCH LIST



Every Hawaiian forest bird species is on the Watch List. There are Watch List species in every major habitat. See the full Watch List of 230 species at **www.stateofthebirds.org.**

*Includes birds of Hawai'i, other U.S. Pacific islands, Puerto Rico, and U.S. Virgin Islands, but not Hawaiian forests

FOREWORD

"The pigeon was no mere bird, he was a biological storm." —*Aldo Leopold*

Passenger Pigeon illustration by Stephen Ridder

The Passenger Pigeon was the most abundant bird America has ever known.

As they migrated en masse up and down the eastern United States, they darkened the skylines of New York, Boston, Chicago, Minneapolis, and St. Louis. In 1860, one flock estimated to be a billion-birds strong was said to be 300 miles long; it took 14 hours, from sunup to sundown, for the flowing river in the sky to pass.

Forty years later, the river had dried up to the last few drops, a single bird or a solitary pair that had thus far escaped market hunting and forest clearing. The last known pigeons in the wild were shot around 1902. Then on September 1, 1914, the very last Passenger Pigeon—a captive bird the keepers at the Cincinnati Zoo called Martha—died.

From billions of birds to none, in half of a person's lifetime.

On this somber 100th anniversary, we do not honor the Passenger Pigeon simply by bemoaning its demise. We honor it by reflecting on what we've learned.

Today, we know how to provide the crucial coastal habitat that has sparked a remarkable turnaround for American Oystercatchers; we know how to modify long-line fishing practices to prevent the accidental catch of endangered Short-tailed Albatrosses; and, we know how to manage jack pine forests in ways that make Kirtland's Warbler populations grow.

If Passenger Pigeons were indicators of our collective indifference toward birds, this fifth State of the Birds report signals how far we've come.

In this report we use birds as indicators of ecosystem health by examining population trends of obligate species for a single habitat (all the bird species dependent primarily on that habitat for survival). This 2014 report marks the fifth State of the Birds, so you will see references to the habitat indicators' trends since 2009. As you read the report, ask yourself, what are the birds telling us about our lands and waters? Aridland birds are rapidly declining, perhaps an echo of environmental conditions and habitat change in the West. Eastern Meadowlarks are disappearing as family farms fade from rural America. Yet wetland birds have staged a robust recovery—with the help of programs that safeguard wetlands such as the North American Wetlands Conservation Act and the federal Duck Stamp, populations of Mallard, Blue-winged Teal, Gadwall, and some other duck species have risen dramatically.

In the Preventing Extinctions section of this report, you'll read about Watch List species that require our immediate conservation attention, and the factors driving their declines. In Preserving Abundance, you'll read about the Common Birds in Steep Decline—those species that still mostly number in the millions but have lost more than half of their global population. Remembering the Passenger Pigeon, we know the importance of keeping common birds common. Surely we can strive for more than Noah's Ark, more than just a representative sampling of species on Earth. Our grandchildren deserve to hear a springtime chorus of meadowlarks calling from the fenceposts, to see wave after wave of sandpipers dancing along the surf, to be amazed by nature not just in its presence, but in its multitudes.

Birds aren't just warning signals; they give us hope. Ducks fly again in great aerial cascades along California's Central Valley and up the Mississippi River and into Chesapeake Bay. California Condors were saved from the brink of extinction, from just 22 birds to more than 200 today. Bald Eagles, Brown Pelicans, Peregrine Falcons—all species once headed the way of the Passenger Pigeon—are now common again.

Today, we have the science, technology, and knowledge to prevent extinctions. Conservation works. When we have the will to conserve, we can make a better future: for birds, for ecosystems, for everyone.

The North American Bird Conservation Initiative U.S. Committee presents this 2014 State of the Birds Report as a collective call for action.

AMERICA'S BIRD HABITATS
CONTINENTAL LANDS AND INLAND WATERS

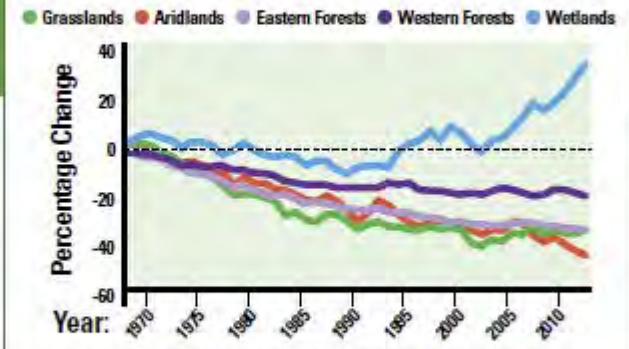
GRASSLANDS
Populations have stabilized at low levels after decades of decline.

Since 1968, the grasslands indicator for 24 obligate breeding birds declined by nearly 40%, but the decline flattened out beginning in 1990. This recent stabilization noted in the 2009 report continues today, reflecting the significant investments made in grassland bird conservation. Reductions in Farm Bill conservation funding, however, threaten those investments.

Eastern grassland birds (such as Eastern Meadowlark and Bobolink) have continued a steady and precipitous decline, associated with declines in pasturelands due to changing dairy farming practices and suburban sprawl.

A sub-group of shortgrass prairie-nesting birds in the Western Great Plains—including Sprague's Pipit and McCown's and Chestnut-collared longspurs—also continue steep declines, which may be driven by large-scale agricultural conversion and overgrazing on their wintering grounds in the Chihuahuan Desert that spans the U.S.–Mexico border.

BIRD POPULATION INDICATORS IN FIVE INLAND HABITATS



See Our Approach for description of bird population indicators.

Conservation works! Rangewide grassland bird conservation depends on conservation provisions in the Farm Bill. For example, Henslow's Sparrow and Upland Sandpiper (which benefit from the Conservation Reserve Program and grazing management on working grasslands, respectively) have responded positively to the many millions of grassland acres put back on the land since 1985. Continued support for Farm Bill conservation programs is needed to lock in these gains.

Upland Sandpiper by Corey Hayes

ARIDLANDS
Although steep declines continue, conservation initiatives are spreading to restore and protect habitat.

The aridlands indicator for 17 obligate birds—breeding birds of desert, sagebrush, and chaparral habitats in the West—is the most steeply declining of all habitat indicators, with an overall loss of 46% since 1968. Just since 2009 this indicator dropped 6%, extending a nearly continuous 44-year decline. Habitat loss and fragmentation due to residential and energy development are the most consistent and widespread threats. Long-term habitat degradation from unsustainable land use, invasions of non-native grasses, and encroachment by trees and shrubs also play significant (and underappreciated) roles in the decline. These negative effects have been exacerbated over the past decade by severe drought, creating extremely difficult conditions for aridland birds such as Bendire's and Le Conte's thrashers, the two fastest declining species in the aridlands indicator.

Conservation works! The NRCS Sage Grouse Initiative is working with more than 1,000 ranchers on privately owned lands within the range of the Greater Sage-Grouse to implement land management practices that benefit both cattle and grouse. The BLM Restore New Mexico initiative has restored 1.8 million acres of aridlands habitat on federal public lands. More large-scale habitat protection and enhancement initiatives are needed to enable aridland birds to persist during prolonged periods of drought, particularly given projections for reduced and more variable precipitation in the Southwest due to climate change.

Greater Sage-Grouse by Gerrit Vyn

Top: Chestnut-collared Longspur by Carrol Henderson; Bottom: Le Conte's Thrasher by Bill Hubick

FORESTS Ongoing declines in the East and West, but progress made in conserving important forest habitats.

The eastern forests indicator for 26 obligate breeding birds shows an overall drop of 32%, with a continued steady decline since 2009. Species dependent on either young forests (such as Golden-winged Warbler and Eastern Towhee) or mature deciduous forest (such as Wood Thrush and Cerulean Warbler) are showing the steepest declines. Because 84% of eastern forests are privately owned, timber companies and other forest owners can greatly benefit bird populations by maintaining large forest blocks and participating in sustainable forestry initiatives.

The western forests indicator, based on 39 obligate breeding species, has declined nearly 20% and has continued to decline since 2009. More than half of western forests are on public lands. Species dependent on oak and pinyon-juniper woodlands (such as Oak Titmouse and Pinyon Jay) are showing the steepest declines. As in the East, both early successional species (such as Rufous Hummingbird and MacGillivray's Warbler) and mature forest species (such as Vaux's Swift and Cassin's Finch) are declining.

Major threats to U.S. forests include urban and ex-urban development, changes in natural disturbance regimes including fire, and exotic insect pests and diseases.

Conservation works! With support from the National Fish and Wildlife Foundation and NRCS Working Lands for Wildlife initiative, state and private partners within the Appalachian Mountains Joint Venture have created 28,000 acres of early successional forest for Golden-winged Warbler and American Woodcock. Similarly, Klamath Siskiyou Oak Network partners have restored 6,000 acres on federal, state, and private lands in southern Oregon and northern California, benefitting oak-dependent birds such as Oak Titmouse. Both are excellent examples of public–private partnerships creating important habitat for declining forest birds.

American Woodcock by Chris Wood

WETLANDS Strong population gains reflect habitat investments, yet wetlands loss continues in some regions.

The inland wetlands indicator for 87 obligate freshwater breeding birds shows strong growth, with a more than 40% gain since 1968. These gains among wetland birds are the continuing legacy of important legislation such as the Clean Water Act and the Farm Bill's conservation provisions.

According to USFWS breeding duck data, Mallards are 42% above their long-term population average. They are just one of several growing waterfowl populations that benefit from dedicated conservation efforts and funding. Federally protected wetlands (such as National Wildlife Refuges), state and local wildlife management areas, and Wetland Reserve Program projects on private lands conserve more than 10 million acres of waterfowl habitat along the four flyways.

Nevertheless, more than 17 million acres of wetlands have been lost since the 1950s. Some wetland bird populations are declining in regions where significant wetlands loss continues. Long-term declines are most apparent in southeastern marsh species such as Mottled Duck, King Rail, and Purple Gallinule, as well as species dependent on ephemeral prairie wetlands including Black Tern, Le Conte's Sparrow, and Northern Pintail.

Conservation works! The North American Wetlands Conservation Act has enabled strategic conservation projects covering an area larger than Tennessee. Implemented by the USFWS and using a partnership approach, this model of public–private cooperative conservation has protected or restored wetlands that contributed to reversing declines of Mallard and other waterfowl species. Just as impressive, the Joint Ventures program has proven to be among the most cost-efficient means of conservation delivery—growing every $1 that Congress provides into $36 in total conservation funding to provide more than 20 million acres of habitat for migratory birds and other wildlife.

Mallards by Diane Mayzak

Top: MacGillivray's Warbler by Gerrit Vyn; Bottom: Purple Gallinule by Alessandro Abate, http://sandrophotos.com/

AMERICA'S BIRD HABITATS OCEANS, COASTS, AND ISLANDS

COASTS Rising wintering populations along seashores.

The coasts indicator for 50 bird species that winter along U.S. coasts has steadily risen 28% above the baseline assessment in 1968, with an 8% rise over the past 5 years—a testament to the wise investments in more than 160 coastal national wildlife refuges and 595,000 acres of national seashore in 10 states. Nevertheless, birds along America's coastlines face threats from development, increased recreational use, and rising sea levels due to climate change.

Along the Pacific Coast, Black Turnstones and Black Oystercatchers show encouraging population increases. However, human-caused disturbances and habitat loss are negatively affecting California populations of wintering Dunlins and threaten resident populations of Snowy Plovers.

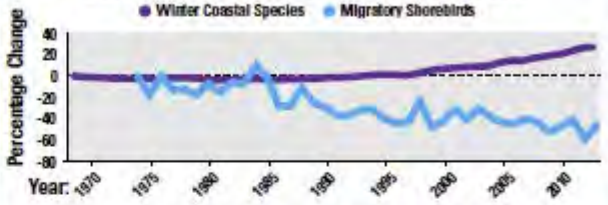
Along the Gulf of Mexico, the Deepwater Horizon oil spill affected Black Skimmers and Wilson's Plovers, two coastal species already in decline. Deepwater Horizon–related funding will be critical to address environmental damage from the oil spill in a timely manner. Meanwhile, Gulf coastal wetlands loss continues; coastal habitats will need additional conservation measures to counter wetlands loss and sea-level rise.

Birds along the Atlantic Coast are squeezed for habitat in this most densely human-populated region of the U.S. Additionally, coastal engineering projects—such as sea walls being built to defend against sea-level rise—are impacting beach-nesting species such as Piping Plover and tidal marsh birds such as Saltmarsh Sparrow.

Conservation works!

Coastal wetland restoration projects are showing that natural habitats offer the best resilience to rising waters. The Nature Conservancy's South Cape May Meadows in New Jersey provides important habitat for birds such as the endangered Piping Plover, and the preserve acted as a natural buffer during Superstorm Sandy, holding back the sea surge and floodwaters.

COASTAL AND SHOREBIRD INDICATORS



See Our Approach for description of bird population indicators.

SHOREBIRDS Long-distance migrants are steeply declining and need international conservation.

Shorebirds are declining more than many other species groups. Long-term migration counts for 19 shorebird species show an alarming 50% decline since 1974. Declines are particularly strong for long-distance migrants that breed in the Arctic and boreal forest. Species with the steepest declines include Red Knot, Hudsonian Godwit, and Ruddy Turnstone. Long-distance migrants require healthy stopover habitats along their entire pathway, and the chain of sites is only as strong as the weakest link. For example, overharvesting of horseshoe crab eggs in Delaware Bay can threaten the entire Atlantic coastal population of Red Knots, as they depend on this food source during their intercontinental migration. Cooperative international efforts are needed to improve the outlook for Red Knots and other winged ambassadors.

Conservation works! In response to alarming declines among Atlantic Flyway shorebird populations, the USFWS, National Fish and Wildlife Foundation, and partners created the Atlantic Shorebird Business Strategy. The strategy uses business planning fundamentals to tie funding inputs to measurable results. NFWF investments in priority action areas have already stopped a regional decline of American Oystercatchers and increased reproductive success. Now the population is growing for the first time in 10 years.

American Oystercatcher by Michael Libbe, www.michaellibbephotography.com

Left: Black Skimmers by Gerrit Vyn; Right: Piping Plover by Ray Hennessy

OCEANS Many seabirds face severe threats; marine protected areas and a fishing treaty can help birds on the ocean.

Because oceans are vast habitats, there isn't enough broad bird population survey data for an oceans habitat indicator. However, regional surveys and research identify important habitat for seabirds, as well as potential threats—including fishing operations that deplete prey fish stocks, offshore energy development (wind power generation and gas and mineral exploration), and oil spills in critical marine foraging habitats.

In the North Atlantic, colony counts of some species (such as Northern Gannets) indicate stable or growing populations. Others (such as Arctic Terns in the Gulf of Maine) have seen large declines linked to lowered breeding productivity and changes in availability of prey fish species, due to changing ocean temperatures.

In Alaskan waters, USFWS surveys mostly show stability in seabird populations, though Aleutian Tern and Kittlitz's Murrelet colonies are in steep decline. Point Blue Conservation Science surveys in the California Current ecosystem show Common Murre, Pigeon Guillemot, and Cassin's Auklet populations have recovered from past breeding failures. However, Brandt's Cormorants and Western Gulls have suffered severe population declines, signaling the depletion of important prey such as anchovy and sardine.

Plastic pollution continues to be a problem, including a massive garbage patch in the Pacific. In one study, more than 90% of Northern Fulmars found dead on beaches had plastic in their stomachs, mostly consumer-grade plastics (e.g. toothbrushes).

Seabird populations will benefit from the proposed expansion of marine protected areas to 782,000 square miles of American waters in the Pacific.

Laysan Albatross by Gerrit Vyn

Conservation works! The U.S. commercial fishing industry in the Pacific Ocean has made great strides in adopting bird-friendly practices. In Alaska, the use of streamers on long-line fishing boats to scare away birds reduced incidental bycatch by more than 50% from 2007 to 2012. U.S. fishing fleets use measures consistent with the Agreement on the Conservation of Albatrosses and Petrels, which seeks to conserve 30 species of albatrosses and petrels. Thirteen countries have joined the ACAP treaty, including some of the world's leading fishing nations such as Peru and Chile, but not the U.S. Signing ACAP would demonstrate U.S. leadership to other countries in the Pacific—such as Japan, China, and South Korea—and level the playing field for American fleets, since other countries would adopt the bird-friendly fishing practices that the U.S. already uses.

ISLANDS Immediate help is needed for many island birds making their last stand.

Island birds are especially restricted by where they can live, and those restrictions tighten when development and nonnative predators and plants consume the limited supply of habitat. Such is the case on Hawai`i, where avian malaria; predation by introduced rats, cats, and mongooses; pressure by grazing ungulates, such as sheep, goats, and pigs; and habitat degradation by invasive plants are pushing several species toward extinction. One-third of all of America's federally endangered birds are Hawaiian species.

On other American islands, invasive species are likewise taking a sizable toll on endemic birds. The brown tree snake is a menace on Guam and the Northern Mariana Islands, responsible for nine extinctions and extirpations within the last 50 years. Efforts are underway to relocate imperiled species such as Bridled White-eye to snake-free islands. The last remaining population of Mariana Crow on the island of Rota is imperiled by feral cats. Several species on American Samoa and U.S. territories in the Caribbean, such as Spotless Crake and Puerto Rican Parrot, face critical shortages of quality habitat.

Conservation works! Relocations of Millerbirds and Laysan Ducks in the Northwestern Hawaiian Islands are increasing the populations of those species and reducing their risk of extinction. The 'Alalā has been absent in the wild on Hawai'i Island for more than a decade, but captive breeding has kept the species alive and grown its population. Work is now underway to prepare habitat for reintroductions.

Hawai'i 'Amakihi by Jack Jeffrey

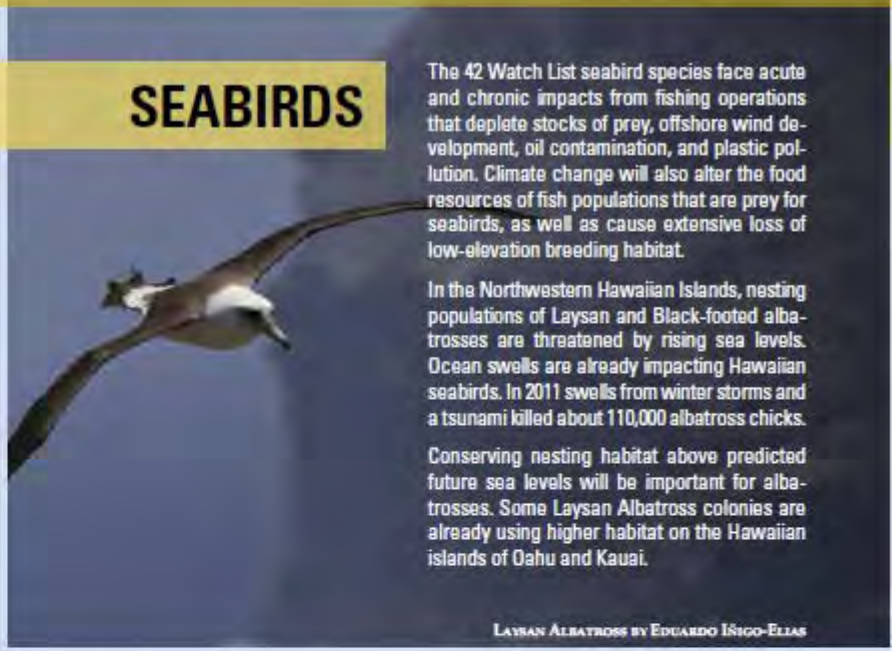
Top: Common Murres by Gerrit Vyn; Bottom: Mariana Fruit Dove by Jack Jeffrey

PREVENTING EXTINCTIONS

The State of the Birds Watch List contains the 230 species most in need of conservation action. (See the full list at www.stateofthebirds.org.) Without conservation action, these are the birds headed the way of the Passenger Pigeon and other now-extinct American birds, such as the Carolina Parakeet and Heath Hen. Watch List birds meet criteria for a combination of high rate of population decline, small population size, small geographic range, and significant future threats to sustainable populations.

The Watch List contains species already on the federal Endangered list as well as those at risk of becoming Threatened or Endangered. While the Endangered Species Act remains the primary line of defense against extinction, proactive conservation is the most effective way to keep other Watch List species from needing Endangered list protection. Most Watch List species fall into seven categories; addressing issues across landscapes and migratory ranges can efficiently conserve entire suites of at-risk species.

SEABIRDS



The 42 Watch List seabird species face acute and chronic impacts from fishing operations that deplete stocks of prey, offshore wind development, oil contamination, and plastic pollution. Climate change will also alter the food resources of fish populations that are prey for seabirds, as well as cause extensive loss of low-elevation breeding habitat.

In the Northwestern Hawaiian Islands, nesting populations of Laysan and Black-footed albatrosses are threatened by rising sea levels. Ocean swells are already impacting Hawaiian seabirds. In 2011 swells from winter storms and a tsunami killed about 110,000 albatross chicks.

Conserving nesting habitat above predicted future sea levels will be important for albatrosses. Some Laysan Albatross colonies are already using higher habitat on the Hawaiian islands of Oahu and Kauai.

Laysan Albatross by Eduardo Iñigo-Elias

SHOREBIRDS

Shorebirds are among the most threatened groups of North American birds. More than half of U.S. shorebird species are on the Watch List, including beach-nesting Piping and Wilson's plovers, prairie-nesting Mountain Plover and Long-billed Curlew, and arctic-nesting Red Knot and Hudsonian Godwit.

The small size of many shorebird populations, and their tendency to concentrate in small areas during migration and winter, make them especially vulnerable to human disturbance, loss of coastal and freshwater wetlands, and unregulated harvest in the Caribbean and South America.

Shorebirds will respond rapidly to protection and active management, such as providing shallow water impoundments or seasonally flooded rice fields. The Western Hemisphere Shorebird Reserve Network recognizes more than 32 million acres of key habitats throughout the Americas.

Red Knot by Gerrit Vyn

ARIDLANDS/ GRASSLANDS

Thirty Watch List species are specialized birds of grasslands, deserts, sagebrush, and chaparral—some of the most neglected and maligned habitats in America. These are places where development, intense agricultural production, and energy extraction are primary land uses.

Among the most threatened species are Greater and Lesser prairie-chickens and Greater and Gunnison sage-grouse. These spectacular dancing birds still perform their spring breeding rituals across 18 states in the Midwest and West.

Cooperative conservation habitat initiatives are enlisting ranchers and farmers to help keep these iconic American birds on the land. Conservation efforts on private working lands must be coordinated with improved management across vast western public lands to reverse the declines not only of prairie-chickens and grouse, but also thrashers, sparrows, and longspurs.

Greater Prairie-Chicken by Gerrit Vyn

COASTAL

Coasts, beaches, and salt marshes provide habitat for 36 Watch List species, including endangered Piping Plover and Whooping Crane, 20 species of shorebirds, and the entire population of Saltmarsh Sparrow. Reddish Egrets depend on mangrove and estuary systems along our southern coasts, while Steller's and Spectacled eiders occur only along Alaska's Arctic coasts.

Coastal birds face multiple threats from human development and disturbance, oil spills and other pollution, and more recently from climate change—in the form of rising sea levels and severe coastal storms.

Our network of national seashores, national wildlife refuges, and private preserves offer protection for coastal birds in many regions, but more widespread efforts to restore coastal wetlands and reduce disturbance to beach-nesting birds will be needed.

Emperor Goose by Gerrit Vyn

NEOTROPICAL MIGRANTS

Thirty Watch List species are Neotropical migrant songbirds that breed in North America and winter south of U.S. borders.

Neotropical migrant conservation requires international cooperation to protect habitats throughout their ranges, on the premise that conservation in Latin America and the Caribbean will ensure these birds return to the U.S. in spring. Bicknell's Thrush, a breeding bird of Northeastern mountains, needs immediate action to stop deforestation in Hispaniola. Virginia's Warbler and Rufous Hummingbird both breed in the West and winter in Mexican pine-oak and thorn forests.

Cerulean and Golden-winged warblers breed in eastern forests and winter in the tropics. These fast-declining species have benefitted from collaborations by scientists, agencies, and businesses that created breeding habitat on U.S. timberlands and wintering habitat in Colombian coffee-growing landscapes. Such partnerships provide a model for voluntary, international habitat conservation for other Neotropical migrants.

Cerulean Warbler by Gerrit Vyn

HAWAIIAN FOREST

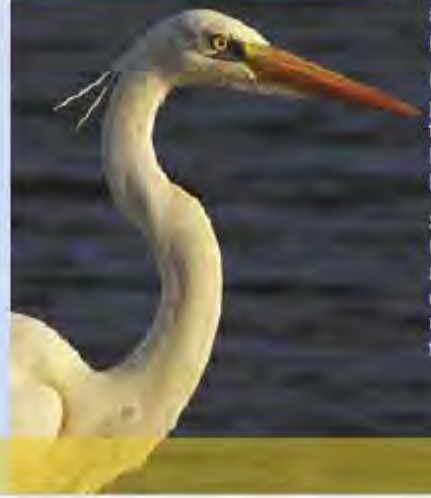
All 33 native Hawaiian forest bird species are on the Watch List; 23 are federally endangered. Hawai`i may be a tourist paradise, but it's the bird extinction capital of the world. No place has had more bird extinctions since human settlement.

Eleven Hawaiian forest bird species have dangerously low populations of fewer than 5,000 individuals, including Palila and `Akiapōlā`au. Non-native predators and disease-bearing mosquitoes pose the biggest threats, especially to forest birds on Kauai. Mosquitoes are expanding into high-elevation forests as temperatures become warmer.

Where conservation has been enacted, there is hope. Ungulate-proof fences are effective in protecting forests. Some species (including `Apapane and Hawai`i `Amakihi) are evolving resistance to avian malaria. More Hawaiian forest birds will fight for their own survival, if people give them a fighting chance through habitat conservation.

`I`iwi by Jack Jeffrey

DISTINCT POPULATIONS



Genetically distinct populations within a single species are important reservoirs of evolutionary diversity. Quite often, upon closer examination by scientists, some of these so-called subspecies are recognized as entirely unique species of their own, as with Bicknell's Thrush and Bell's Sparrow. Many of these distinct populations meet Watch List criteria.

Often distinct populations are isolated and pressures on their limited habitat threaten their existence. For example, the Great White Heron nests only in the mangroves of the Florida Keys.

Some distinct populations, such as the Yuma Clapper Rail and Florida Grasshopper Sparrow, are already protected as federally endangered. Proactive conservation for other regionally distinct bird populations will protect the full diversity of American birdlife.

Great White Heron by Tom Blandford, tomblandford.smugmug.com

PRESERVING ABUNDANCE

Birds that are abundant today can undergo a massive population collapse with surprising rapidity. Passenger Pigeon populations crashed from 2 to 3 billion birds to none in the wild in just 40 years. Keeping common birds common, while we still can, is as important as preventing extinctions of rare species.

Today there are 33 common bird species that do not meet Watch List criteria, yet are rapidly declining in many areas. (See the full list at www.stateofthebirds.org). These birds have lost more than half their global population. All of these species combined have lost hundreds of millions of breeding individuals over the past four decades.

Most common birds in steep decline fall within five categories that indicate larger environmental trends. Addressing the conservation needs of these birds will result in healthier, more productive lands and waters for other wildlife, as well as people.

GAMEBIRDS

America's resident gamebirds are some of our most beloved wildlife. Yet even with the best efforts by state agencies and private conservation groups to manage gamebird populations and foster recovery in some areas, many of these species continue to decline.

For example, Northern Bobwhite has benefitted from dedicated conservation efforts in targeted areas, yet it's declining steeply across its range. Scaled Quail is exhibiting broad population declines across the Southwest.

Both of these birds occur in agriculturally dominant landscapes and depend on working lands conservation. Rangewide recovery requires taking best practices—such as grass buffers along cropfields for bobwhite and prescribed burns with grazing management for Scaled Quail—and extending them across landscapes. Gamebirds will also benefit from management for other, non-game grassland and aridland birds.

Northern Bobwhite by Joshua Clark; www.momentsinnature.com

PRAIRIE WETLANDS

Though wetland birds are doing well overall, Black Tern and Northern Pintail are two species with significant declining trends. These birds depend on ephemeral prairie wetlands—those wet spots on the prairie that fill with snowmelt and seasonal rains.

The Prairie Pothole Region of the Upper Midwest is a great cluster of these temporary wetlands. Declining Northern Pintail populations mirror the continuing drainage of ephemeral wetlands in this region. Ephemeral prairie wetlands are among the most threatened wetland ecosystems, as they are largely not protected by the Clean Water Act. From 1997 to 2009, total wetland area in the PPR declined by 74,340 acres.

A provision in the 2014 Farm Bill, called conservation compliance, discourages the drainage and conversion of ephemeral wetlands. The USFWS is directing Duck Stamp revenue toward protecting these vital wetlands and surrounding prairies.

Northern Pintail by Gregory Lis

AERIAL INSECTIVORES

Common Nighthawk, Chimney Swift, and Bank Swallow are three very different bird species, but they all eat flying insects—and they're all declining rapidly.

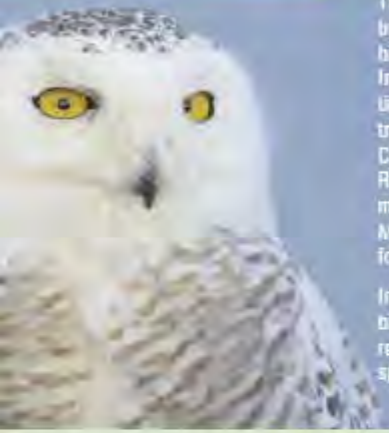
They are also all members of bird families (nighthawks and nightjars, swifts, and swallows) that are broadly declining. Bank Swallow is just one of six swallow species declining across major portions of its range.

Aerial insectivores are extremely sensitive to environmental change. The increased effectiveness and use of agricultural insecticides such as synthetic neonicotinoids has greatly reduced their prey base of flying insects.

Neonicotinoids are also suspected in declines of native pollinators. Decreasing pesticide use, in agriculture and around the home, will benefit bees and butterflies as well as aerial insectivores.

Common Nighthawk by Gerrit Vyn

NORTHERN VISITORS



Many birds that commonly visit the lower 48 states from the North are in steep decline. Shrinking populations of Snowy Owl, which shift south with great fanfare every few winters, may reflect changing climatic conditions in the Arctic. Winter flocks of Snow Buntings are also getting smaller.

The vast boreal forest, mostly in Canada, is a breeding nursery for hundreds of millions of birds that migrate through or winter in the U.S. Increasing timber, oil, and natural gas extraction is impacting boreal bird populations, contributing to long-term declines of Blackpoll, Cape May, and Wilson's warblers, as well as Rusty Blackbird and Pine Siskin. Several new mining projects proposed from Minnesota to Maine would further damage southern boreal forest habitat within the U.S.

International efforts such as the Boreal Songbird Initiative are fostering cross-border research and conservation to stop the widespread decline of northern birds.

Snowy Owl by Gerrit Vyn

RURAL LANDSCAPES

As family farms have disappeared in America, so too have many species of birds that were good neighbors to generations of American farmers.

In the East and Midwest, Eastern Meadowlark and Grasshopper Sparrow populations have declined as industrial farming became widespread. According to the USDA, dairy farming has shifted toward larger operations and away from pasturing practices, which has reduced habitat for these species. In the West and Southwest, as ranchers fight to maintain their way of life, declining birds such as Lark Bunting and Loggerhead Shrike are likewise attempting to hold on to their homes.

Farm Bill and working lands conservation programs have provided habitat for farm and ranch birds, and now organic agriculture is providing a new boost to rural habitat. A one-day bird survey on an organic dairy farm in Minnesota found almost 50 confirmed or possible breeding species.

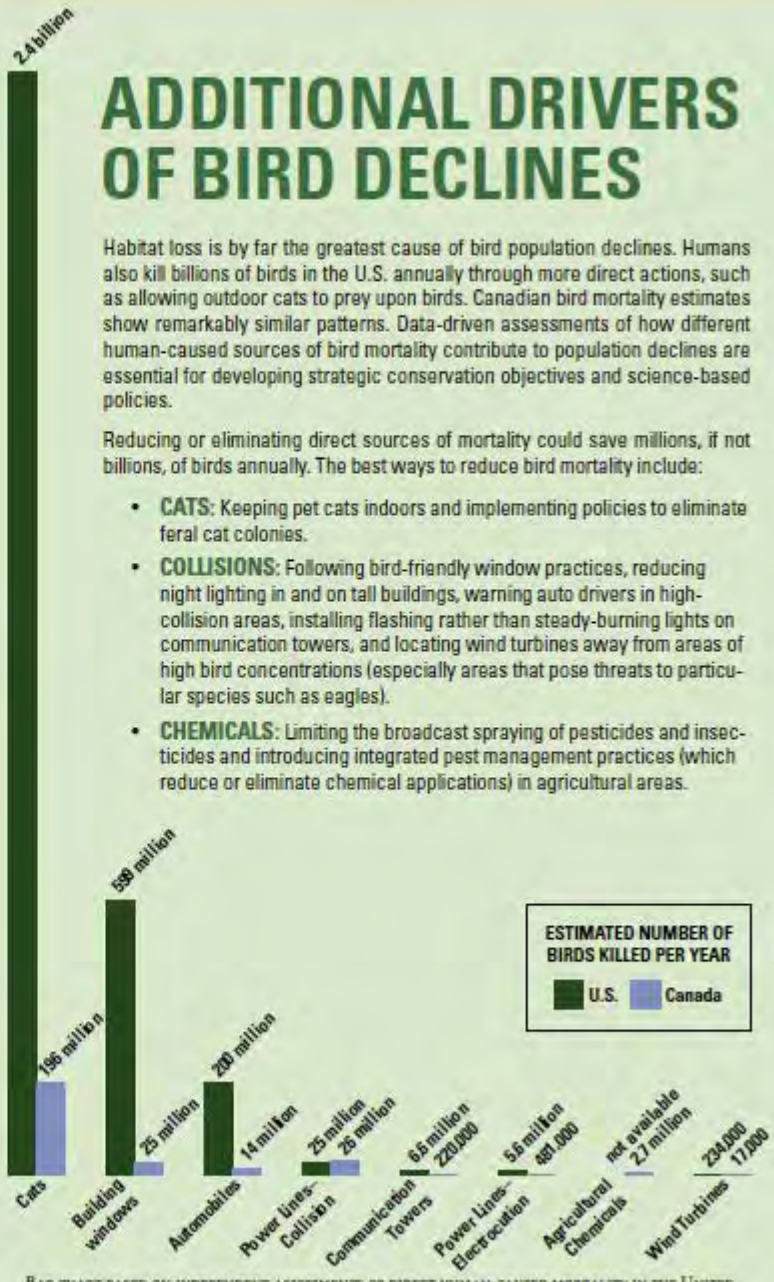
Eastern Meadowlark by Gerrit Vyn

ADDITIONAL DRIVERS OF BIRD DECLINES

Habitat loss is by far the greatest cause of bird population declines. Humans also kill billions of birds in the U.S. annually through more direct actions, such as allowing outdoor cats to prey upon birds. Canadian bird mortality estimates show remarkably similar patterns. Data-driven assessments of how different human-caused sources of bird mortality contribute to population declines are essential for developing strategic conservation objectives and science-based policies.

Reducing or eliminating direct sources of mortality could save millions, if not billions, of birds annually. The best ways to reduce bird mortality include:

- **CATS:** Keeping pet cats indoors and implementing policies to eliminate feral cat colonies.
- **COLLISIONS:** Following bird-friendly window practices, reducing night lighting in and on tall buildings, warning auto drivers in high-collision areas, installing flashing rather than steady-burning lights on communication towers, and locating wind turbines away from areas of high bird concentrations (especially areas that pose threats to particular species such as eagles).
- **CHEMICALS:** Limiting the broadcast spraying of pesticides and insecticides and introducing integrated pest management practices (which reduce or eliminate chemical applications) in agricultural areas.



Bar chart based on independent assessments of direct human-caused mortality in the United States and Canada. This data is adapted from Loss SR, Will T, Marra PP. Direct human-caused mortality of birds. Annual Review of Ecology, Evolution, and Systematics In prep

LESSONS of the PASSENGER PIGEON

The last Passenger Pigeons in the wild were shot just after 1900, a tragic way to start a century. But ironically, their disappearance ushered in a powerful new era of conservation. The pigeon inspired leaders such as Theodore Roosevelt, George Bird Grinnell, Aldo Leopold, and Rachel Carson, and provided the impetus for federal wildlife protection laws, beginning with the Lacey Act, followed by the Migratory Bird Treaty Act, and eventually the Endangered Species Act.

Reflecting back on the plight of the Passenger Pigeon, our nation has made tremendous strides in wildlife conservation. We have developed deep scientific knowledge, built a strong network of protected habitats, and designed the world's best model for adaptive management of wildlife populations. Our charge today is to protect these investments with policies that rise to the threats that wildlife face in the 21st century.

KEY POLICIES FOR AMERICA'S BIRDS

Support and actions on key government policies help keep the assurance to the American public of healthy bird populations for future generations. These policies include:

- The North American Wetlands Conservation Act and Neotropical Migratory Bird Conservation Act;
- Revenue provided by sales of the Duck Stamp;
- The Agreement on the Conservation of Albatrosses and Petrels treaty that endorses America's bird-friendly ocean fishing;
- Conservation programs such as the Land and Water Conservation Fund, Migratory Bird Joint Ventures, and State and Tribal Wildlife Grants;
- The Conservation Reserve Program; and,
- Policies that reduce the impacts of climate change and help birds adapt.

Chris Wood

KNOWLEDGE: Science is the foundation of effective conservation

The population crash of the Passenger Pigeon didn't occur out of sight from human eyes. Americans in the late-19th century could see that the great Passenger Pigeon flocks were growing thinner. But without a mechanism for population monitoring, there was no widespread recognition that the population was in full collapse.

Today scientists have rich data sets for evaluating the health of bird populations. Monitoring allows scientists to inventory bird populations, just as a business takes stock of its assets. Continued monitoring, with years of data for comparison, makes it possible for scientists to gauge population changes. The indicators and assessments in this and previous State of Birds reports were made possible by long-term, consistent monitoring, such as the Breeding Bird Survey, Christmas Bird Count, and eBird. Much of this data is now available to the public and all scientists through the Avian Knowledge Network.

Once declines are detected, causes must be diagnosed. Recent advances in research technologies (such as geolocators small enough to fit on a songbird's back) provide new ways to study birds not possible a decade ago. By locating where the troubles are (on breeding or wintering grounds, or during migration), and what physiological factors play a role (such as DNA or chemical disruption), scientists can pinpoint the limiting factors in a bird population. Out of research comes the prescription for recovery.

Investments in monitoring and research pay for themselves with smarter conservation that's effective and cost-efficient—the kind that keeps species off the Endangered list. Such investments must be planned for up-front in budgeting as a key tool for land management. At the Cascade Siskiyou National Monument, bird monitoring was designated as an indicator of oak woodland ecological integrity. The monitoring data helped guide improved grazing management on 52,000 acres of public lands.

Gerrit Vyn

Courtesy Tom Thulen

HABITAT: America's legacy of healthy habitats needs support

From 1870 to 1900, the number of people in the United States nearly doubled, creating tremendous demand for food and wood products and putting tremendous pressure on mature forests. Deforestation in the Northeast reduced the breeding range of the Passenger Pigeon.

In the wake of the pigeon's demise, a strong conservation movement emerged with a great appreciation for the importance of habitat. President Roosevelt declared the first national wildlife refuge at Pelican Island in 1903. Today, public agencies protect more than 850 million acres of land and 3.5 million square miles of ocean. Private conservation groups and land trusts protect another 24 million acres (an area of private protected habitat nearly as large as the entire National Park Service system in the lower 48 states).

A strong framework of habitat conservation legislation emerged, too. In recent decades, the North American Wetlands Conservation Act and the Neotropical Migratory Bird Conservation Act have conserved more than 30 million acres by growing initial federal investments into higher conservation returns (grant-to-match ratios of more than $3-to-$1). The Farm Bill has had the largest conservation footprint on private lands, with nearly 30 million acres currently enrolled in the Conservation Reserve Program or under farm, grassland, or wetland easements. Additionally, conservation measures are implemented through Farm Bill working lands programs on another 30 million acres on farms and ranches. The Land and Water Conservation Fund has added millions of acres to our national parks, national forests, and wildlife refuges.

These cornerstones of federal legislation have built a great American legacy of healthy habitats. In order to carry the legacy forward for future generations, they must receive continuing authorization and funding at levels closer to their peak appropriations.

MANAGEMENT: Hunters and birders, the conservation constituency

The Passenger Pigeon is a case study in unregulated harvest. At one massive nesting colony in Wisconsin in 1871, one million birds were stuffed into barrels and shipped to market via railroads.

Wildlife management was clearly needed. In the early 20th century, sportsmen ignited a remarkable conservation turnaround. Key legislation, such as the Duck Stamp and the Pittman-Robertson excise tax on firearms and ammunition, built the foundation for funding a wildlife management system. The results of that bold action fly as waves of ducks and geese that course along our country's flyways.

Today, though, our conservation dollars are stretched thin, as the problems are more complex. Climate change poses pervasive threats (changing seasonal temperatures, precipitation patterns, and water levels) that require full-landscape management. Our challenge now is to protect the entire ecological fabric, not just individual threads. It's time to build on the successes of the past century by updating existing revenue streams (the price of a Duck Stamp has not changed since 1991) and expanding the funding base beyond hunter-generated dollars. The 47 million birders in America could be a more powerful source of conservation funding.

Wildlife management in this century must be proactive and partnership-driven. As successful as the Endangered Species Act has been—the lifeline that rescued Bald Eagles and remains fundamental to preventing extinctions—it should be a last resort. We must strive to keep species off the list. Responding to early-warning signals is far more cost efficient and effective than administering emergency care.

The Passenger Pigeon is gone, but we've accomplished much since it disappeared. We may face steeper challenges, but we have a century of progress to build on. And, we know conservation works, when we have the will—and the resources—to achieve it.

OUR APPROACH

Assessment of U.S. Birds by Habitat

Because healthy bird populations depend on both the quality and quantity of their habitats, our State of the Birds approach focuses on species that are dependent on a single primary habitat type—we define these species as habitat obligates. For this report, we identified obligate species in oceans, coasts, inland wetlands, forests, aridlands, and grasslands, as well as species found on Hawai'i, Puerto Rico, and the U.S. Virgin Islands, and other U.S. island territories. A listing of species in each habitat and a map of U.S. habitats based on USGS GAP National Land Cover can be found at www.stateofthebirds.org.

Locations of North American Breeding Bird Survey routes (left) and Audubon Christmas Bird Counts (right), which provided the bulk of long-term bird monitoring data used in this report. Both of these surveys rely on thousands of volunteer birders.

Bird Population Indicators: A Measure of Environmental Health

The underlying principle of State of the Birds reports is that the health of populations of bird species found only within a habitat reflects the overall health of that habitat. To assess the health of bird populations, we used data from several continental-scale monitoring programs that have provided consistent data since 1968 (or since 1974 for shorebirds). For each obligate species, we assigned a habitat type and estimated the population change up to 2012 with the appropriate survey, then combined the estimates of trends for species in the habitat into a composite estimate of change. This composite estimate of change is used as the bird population indicator for the habitat. The statistical approaches we use for estimation of the bird population indicators were first used in the 2009 State of the Birds report.

Tracking Change in U.S. Bird Populations

In this report, we use information from the North American Breeding Bird Survey, the Audubon Christmas Bird Count, the U.S. Fish and Wildlife Service's Spring Breeding Ground Waterfowl Survey, and the American Woodcock Singing-ground Survey. A new indicator was developed from monitoring data of migrating shorebirds, using data from the International Shorebird Survey, the Atlantic Canada Shorebird Survey, and the Ontario Shorebird Survey. Detailed information about these surveys and species used in each analysis are provided on the State of the Birds website (www.stateofthebirds.org).

Species of Conservation Concern: The 2014 State of the Birds Watch List

The Watch List, presented by the North American Bird Conservation Initiative U.S. committee, includes those birds of highest conservation concern occurring in the U.S. and its territories. The 2014 Watch List represents the first time the approach described below has been applied consistently to all of our birds. It includes many of the species listed under the Endangered Species Act, additional species that require immediate conservation attention, and others on or near the brink of being threatened that warrant continued vigilance. The Watch List is re-evaluated every 5 to 10 years on the basis of improved methods of evaluation, better data, and changes in the status of populations. A complete listing of Watch List species and distinct populations is available on the State of the Birds website (www.stateofthebirds.org).

To assess species for inclusion on the Watch List, a NABCI team reviewed the conservation status of more than 800 bird species in the continental U.S., Hawai'i, U.S. oceans, and territories. The team drew on data from long-term monitoring surveys, regional assessments, and expert knowledge of species' populations and threats to each major habitat. Specifically, we assessed the vulnerability of each species to possible extinction, based on six key factors: size of global breeding population, breeding and non-breeding range size, threats to breeding and non-breeding habitats, and population trends. Species that did not meet Watch List criteria for threats or range size, but experienced significantly declining trends (50% or more loss over 45 years), are defined as Common Birds in Steep Decline. The complete results of this assessment can be found in the Partners in Flight Species Assessment Database maintained by the Rocky Mountain Bird Observatory.

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Thank You to Volunteers: We thank the thousands of dedicated bird watchers who volunteer their time and expertise to participate in long-term monitoring programs such as the North American Breeding Bird Survey, Christmas Bird Count, and eBird. Without their efforts, we would not have the understanding of bird population status and trends that made this State of the Birds Report possible.

ABOUT NABCI AND THE U.S. STATE OF THE BIRDS REPORTS

The development of the State of the Birds report is a team effort lead by the North American Bird Conservation Initiative U.S. Committee. The NABCI U.S. Committee is a forum of 23 state and federal government agencies, private conservation organizations, and bird initiatives that work together in partnership so that healthy populations of North American birds are enjoyed and valued for generations to come. Beginning in 2009, NABCI has produced four U.S. State of the Birds reports that focus on key issues such as climate change and public and private lands conservation. This report is the fifth in the series.

2009 2010 2011 2013

DEDICATED TO THE MEMORY OF RUSS GREENBERG (1953–2013)

Russ Greenberg was one of the key scientists in the nascent field of conservation biology who became alarmed by tropical deforestation. In response, he proposed the idea of promoting shade-grown coffee as a bird-friendly product. His ability to integrate science and conservation was especially evident in his research on Neotropical migrants, culminating in 1989 with a landmark paper with Chan Robbins, John Sauer, and Sam Droege indicating precipitous population declines of migratory species. This paper motivated Congress to appropriate funds to establish the Smithsonian Migratory Bird Center and helped ignite a massive bird conservation movement resulting in the establishment of Partners in Flight. Russ also initiated important public initiatives, including the Bridging the Americas program to teach schoolchildren about migratory birds and a popular public festival that blossomed into International Migratory Bird Day. Russ will always be remembered as a great champion in migratory bird conservation.

Russ Greenberg on Santa Cruz Island, California by Maybellene Gamboa

The Cornell Lab of Ornithology

nabci

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Klamath Bird Observatory

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American Bird Conservancy

United States Shorebird Conservation Plan

National Park Service

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THE FUTURE OF WIND ENERGY

APEX CLEAN ENERGY

Executive Summary

Wind Vision:

A New Era for Wind Power in the United States

This report is being disseminated by the Department of Energy. As such, the document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by the Department of Energy. Though this report does not constitute "influential" information, as that term is defined in DOE's information quality guidelines or the Office of Management and Budget's Information Quality Bulletin for Peer Review (Bulletin), as detailed in Appendix N, the report was reviewed both internally and externally prior to publication.

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Message from the Director

The wind industry can be characterized by the substantial growth of domestic manufacturing and the level of wind deployment seen in recent years. Wind power systems are now seen as a viable and competitive source of electricity across the nation. Wind power's emerging role is an important option in a portfolio of new energy solutions for future generations. More than 4.5% of our nation's electricity came from wind power in 2013, placing the industry at a crossroads between the opportunities of higher energy penetration and the challenges of increased competition, policy uncertainty, access to transmission and lower energy demand.

The primary goal of the *Wind Vision* was to gain insights, after analyzing and quantifying a future scenario for wind energy, that consider our domestic manufacturing capacity, current and projected cost trends, sensitivities to future demand and fuel prices, and transmission needs. The *Wind Vision* was accomplished by bringing together leaders in energy in an effort to pool their insights, build upon their advancements, and learn from their accomplishments to project a credible future supported by the economic and societal benefits of wind energy.

In writing the *Wind Vision,* we recognize that the Energy Department is not the sole agent to drive a new future for the industry, but the federal Wind Program can provide focus and direction by leading efforts to accelerate the development of next-generation wind power technologies and assisting in solving key market challenges.

I would like to express my deepest sense of gratitude to the hundreds of individuals across our agency, industry, academia, and our national labs for their support, feedback and strategic interest in a renewed vision for wind energy. Their level of involvement signals a bright future for the wind industry.

The stakes for the nation are high. I am confident that, with sustained leadership in innovation, U.S. wind power will continue to make a significant contribution to the ever-evolving energy landscape. The *Wind Vision* is intended to assist in prioritizing the decisions needed to increase the economic competitiveness of the U.S. wind industry throughout the 21st century.

José Zayas
Director, Wind and Water Power Technologies Office
U.S. Department of Energy
March 12, 2015

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Executive Summary: Overview

The U.S. Department of Energy's (DOE's) Wind and Water Power Technologies Office led a comprehensive analysis to evaluate future pathways for the wind industry. Through a broad-based collaborative effort, the *Wind Vision* had four principal objectives:

1. Documentation of the current state of wind power in the United States and identification of key technological accomplishments and societal benefits over the decade leading up to 2014;
2. Exploration of the potential pathways for wind power to contribute to the future electricity needs of the nation, including objectives such as reduced carbon emissions, improved air quality, and reduced water use;
3. Quantification of costs, benefits, and other impacts associated with continued deployment and growth of U.S. wind power; and
4. Identification of actions and future achievements that could support continued growth in the use and application of wind-generated electricity.

The conclusions of this collaborative effort, summarized below, demonstrate the important role that wind power has in the U.S. power sector and highlight its potential to continue to provide clean, reliable and affordable electricity to consumers for decades to come. The *Wind Vision* study does not evaluate nor recommend policy actions, but analyzes feasibility, costs, and benefits of increased wind power deployment to inform policy decisions at the federal, state, tribal, and local levels.

A High U.S. Wind Penetration Future is Achievable, Affordable and Beneficial

Wind power is one of the fastest-growing sources of new electricity capacity and the largest source of new renewable power generation added in the United States since 2000. Changes in wind power market dynamics, costs, technology, and deployment since the 2008 DOE report, *20% Wind Energy by 2030,* are documented through analysis of recent history, current status (as of 2013), and projected trends. The analysis of wind installation and operational experience as of 2013 concludes that:

- Wind deployment, including associated manufacturing and installation activities, has demonstrated the ability to scale to satisfy rapid build demands, including the deployment levels of the *Wind Vision Study Scenario* described below;
- Wind generation variability has a minimal and manageable impact on grid reliability and related costs; and
- Environmental and competing use challenges for local communities, including land use, wildlife concerns, and radar interference issues, can be effectively managed with appropriate planning, technology, and communication among stakeholders.

Deployment of wind technology for U.S. electricity generation provides a domestic, sustainable, and essentially zero-carbon, zero-pollution and zero-water use U.S. electricity resource.

The *Wind Vision* report deepens the understanding of U.S. wind power's potential contributions to clean, reliable electricity generation and related economic and other societal benefits. Results are provided from analyses of U.S. greenhouse gas (GHG) and pollution reductions, electricity price impacts, job and manufacturing trends, and water and land use impacts—for the years 2020, 2030, and 2050. A high U.S. wind penetration is achievable but will require actions as identified in the *Wind Vision* Roadmap.

Study Summary

The *Wind Vision* report results from a collaboration of the DOE with over 250 experts from industry, electric power system operators, environmental stewardship organizations, state and federal governmental agencies, research institutions and laboratories, and siting and permitting stakeholder groups. The *Wind Vision* report updates and expands upon the DOE's 2008 report, *20% Wind Energy by 2030,* through analysis of scenarios of wind power supplying 10% of national end-use electricity demand by 2020, 20% by 2030, and 35% by 2050. This *Study Scenario* provides a framework for conducting detailed quantitative impact

analyses. The *Wind Vision* analysis concludes that it is both viable and economically compelling to deploy U.S. wind power generation in a portfolio of domestic, low-carbon, low-pollutant power generation solutions at the *Study Scenario* levels. Realizing these levels of deployment, however, would depend upon both immediate and long-term actions—principally identifying continued wind cost reductions, adding needed transmission capacity, and supporting and enhancing siting and permitting activities—to complement any federal, state, tribal, and local policies that may be enacted. Described in the *Wind Vision* Roadmap, these actions focus on specific key challenges and stakeholder actions that should be considered.

Analysis Overview

The *Wind Vision* analysis models three core scenarios in order to better understand the sensitivities in deployment to various external drivers and, subsequently, to understand the likely economic and environmental effects of those drivers on the scenarios; a *Baseline Scenario*, with U.S. wind capacity held constant at 2013 levels of 61 gigawatts (GW); a *Business-as-Usual Scenario* (*BAU*), and a *Study Scenario*. The *BAU Scenario* is used to evaluate the industry's domestic economic competitiveness today and into the future based on central expectations of future fossil fuel and renewable costs, energy demand, scheduled existing fleet retirements, and federal and state policies enacted as of January 1, 2014.

The *Study Scenario* starts with current manufacturing capacity (estimated at 8-10 GW of nacelle assembly and other large turbine components within the U.S. today) and applies central projections for variables such as wind power costs, fossil fuel costs, and energy demand in order to arrive at a credible projected pathway that would maintain the existing industry, for purposes of calculating potential social and economic benefits. The *Study Scenario* is a plausible outcome, representing what could come about through a variety of pathways, including aggressive wind cost reductions, high fossil fuel costs, federal or state policy support, high demand growth, or different combinations of these factors. The resulting *Study Scenario*—10% by 2020, 20% by 2030, and 35% by 2050 wind energy as a share of national end-use electricity demand—is compared against the *Baseline Scenario* to estimate costs, benefits, and other impacts associated with potential future wind deployment.

National average wind costs are rapidly approaching cost competitive levels, but, without incentives, these costs are higher than the national average for natural gas and coal costs as of 2013. With continued cost reductions, the *Wind Vision* analysis envisions new wind power generation costs to be below national average costs for both new and existing fossil plants within the next decade.

The *Wind Vision* study concludes that with continued investments in technology innovation, coupled with a transmission system that can provide access to high resource sites and facilitate grid integration reliably and cost-effectively, the *Study Scenario* is an ambitious yet viable deployment scenario. Further, the analysis concluded that the U.S. wind supply chain has capacity to support *Study Scenario* wind deployment levels, with cumulative installations of 113 GW of generating capacity by 2020, 224 GW by 2030, and 404 GW by 2050, building from 61 GW installed as of the end of 2013.

Results: Overall Positive Benefit to the Nation

The *Wind Vision* concludes that U.S. wind deployment at the *Study Scenario* levels would have an overall positive economic benefit for the nation. Numerous economic outcomes and societal benefits for the *Study Scenario* were quantified, including:*

- An approximately 1% increase in electricity costs through 2030, shifting to long-term cost savings of 2% by 2050. This results in cumulative system cost savings of $149 billion by 2050.
- Cumulative benefits of $400 billion (net present value 2013-2050) in avoided global damage from GHGs with 12.3 gigatonnes of avoided GHG emissions through 2050. Monetized GHG benefits exceed the associated costs of the *Study Scenario* in 2020, 2030, and 2050 and on a cumulative basis are equivalent to a levelized global benefit from wind energy of 3.2¢/kWh of wind.
- Cumulative benefits of $108 billion through 2050 for avoided emissions of fine particulate matter (PM), nitrogen oxides (NO_x), and sulfur dioxides (SO_2). Monetized criteria air pollutant benefits exceed the associated costs of the *Study Scenario*

*Quantitative results presented in this Overview are based on the *Central Study Scenario*, defined on Page xxviii. Modeling analysis is based on current (as of 2013) and projected trend data to inform inputs, assumptions, and other constraints. Financial results are reported in 2013$ except where otherwise noted.

in 2020, 2030, and 2050, and on a cumulative basis are equivalent to a levelized public health benefit from wind energy of 0.9¢/kWh of wind.

- Quantified consumer cost savings of $280 billion through 2050 from reduced natural gas prices outside of the electricity sector, in response to reduced demand for natural gas and its price elasticity. This is equivalent to a levelized consumer benefit from wind energy of 2.3¢/kWh of wind.
- A 23% reduction in water consumed by the electric sector in 2050, with significant value in locations with constrained water availability.
- Transmission capacity expansion similar to recent national transmission installation levels of 870 miles per year, assuming equivalent single-circuit 345-kilovolt lines with a 900-MW carrying capacity.
- Land use requirements for turbines, roads, and other wind plant infrastructure of 0.04% of contiguous U.S. land area in 2050.

The *Study Scenario* also identifies certain other impacts, such as those to wildlife and local communities. It does not, however, monetize these impacts, which are highly dependent on specific locational factors.

Roadmap for Key Stakeholder Actions

The *Wind Vision* analysis concludes that, while the *Study Scenario* is technically viable and economically attractive over the long run, a number of stakeholder actions should be considered to achieve the associated wind deployment levels. Improving wind's competitive position in the market can help the nation maintain its existing wind manufacturing infrastructure and the wide range of public benefits detailed in the *Wind Vision*, including reducing carbon emissions. The *Wind Vision report* outlines a roadmap for moving forward and identifies the following key activities, developed collaboratively with industry and stakeholders:

- Reducing wind power costs;
- Expanding the developable areas for wind power; and
- Deploying wind in ways that increase economic value for the nation, including support for U.S. jobs and U.S. manufacturing.

Wind cost reductions do not depend on disruptive technological breakthroughs, but do rely on continued cost improvements, including rotor scale-up; taller towers to access higher wind speeds; overall plant efficiency improvements achieved through advanced controls; improved plant designs enabled by deepened understanding of atmospheric physics; installation of both intra-region and inter-region transmission capacity to high quality wind resource locations; and collaboration and co-existence strategies for local communities and wildlife that support the timely and cost-effective installation of wind power plants.

Risk of Inaction

Wind's growth over the decade leading to 2014 has been driven largely by wind technology cost reductions and federal and state policy support. Without actions to support wind's competitive position in the market going forward, the nation risks losing its existing wind manufacturing infrastructure and much of the public benefit illustrated by the *Wind Vision* analysis.

Conclusions

The *Wind Vision* analysis demonstrates the economic value that wind power can bring to the nation, a value exceeding the costs of deployment. Wind's environmental benefits can address key societal challenges such as climate change, air quality and public health, and water scarcity. Wind deployment can provide U.S. jobs, U.S. manufacturing, and lease and tax revenues in local communities to strengthen and support a transition of the nation's electricity sector towards a low-carbon U.S. economy. The path needed to achieve 10% wind by 2020, 20% by 2030, and 35% by 2050 requires new tools, priorities, and emphases beyond those forged by the wind industry in growing to 4.5% of current U.S. electricity demand. Consideration of new strategies and updated priorities as identified in the *Wind Vision* could provide substantial positive outcomes for future generations.

The *Study Scenario* results in cumulative savings, benefits, and an array of additional impacts by 2050.

System Costs[a]	Benefits[b,c]		
$	GHG	Air Pollution	H_2O
$149 billion (3%) lower cumulative electric sector expenditures	14% reduction in cumulative GHG emissions (12.3 gigatonnes CO_2-equivalents), saving $400 billion in avoided global damages	$108 billion savings in avoided mortality, morbidity, and economic damages from cumulative reductions in emissions of SO_2, NO_x, and PM 21,700 premature deaths from air pollution avoided	23% less water consumption and 15% less water withdrawals for the electric power sector

Additional Impacts

Energy Diversity	Jobs	Local Revenues	Land Use	Public Acceptance and Wildlife
Increased wind power adds fuel diversity, making the overall electric sector 20% less sensitive to changes in fossil fuel costs. The predictable, long-term costs of wind power create downward price pressure on fossil fuels that can cumulatively save consumers $280 billion from lower natural gas prices outside the electric sector.	Approximately 600,000 wind-related gross jobs spread across the nation.	$1 billion in annual land lease payments $440 million annual lease payments for offshore wind plants More than $3 billion in annual property tax payments	Less than 1.5% (106,000 km^2) of contiguous U.S. land area occupied by wind power plants Less than 0.04% (3,300 km^2) of contiguous U.S. land area impacted by turbine pads, roads, and other associated infrastructure	Careful siting, continued research, thoughtful public engagement, and an emphasis on optimizing coexistence can support continued responsible deployment that minimizes or eliminates negative impacts to wildlife and local communities

Note: Cumulative costs and benefits are reported on a Net Present Value basis for the period of 2013 through 2050 and reflect the difference in impacts between the *Central Study Scenario* and the *Baseline Scenario*. Results reported here reflect central estimates within a range; see Chapter 3 for additional detail. Financial results are reported in 2013$ except where otherwise noted.

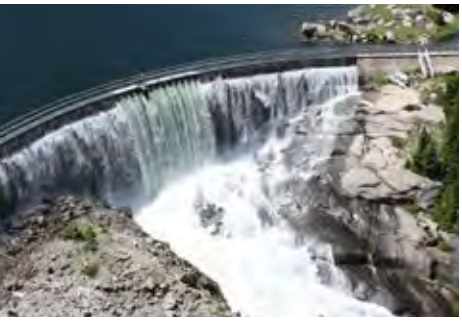
a. Electric sector expenditures include capital, fuel, and operations and maintenance for transmission and generation of all technologies modeled, but excludes consideration of estimated benefits (e.g., GHG emissions).

b. Morbidity is the incidence of disease or rate of sickness in a population.

c. Water consumption refers to water that is used and not returned to the source. Water withdrawals are eventually returned to the water source.

THE OUTLOOK FOR RENEWABLE ENERGY IN AMERICA

2014



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ACORE
American Council On Renewable Energy

ABOUT ACORE

The American Council On Renewable Energy (ACORE), a 501(c)(3) non-profit membership organization, is dedicated to building a secure and prosperous America with clean, renewable energy. ACORE seeks to advance renewable energy through finance, policy, technology, and market development and is concentrating its member focus in 2014 on National Defense & Security, Power Generation & Infrastructure, and Transportation. Additional information is available at: www.acore.org.

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EXECUTIVE SUMMARY

The Outlook for Renewable Energy in America: 2014 assesses the marketplace and forecasts the future of each renewable energy technology sector from the perspectives of U.S. renewable energy trade associations. Each sector forecast is accompanied by a list of the trade association's specific policy recommendations that they believe might encourage continued industry growth.

Renewable energy has now become a technology of choice for many Americans, accounting for nearly 40% of all new, domestic power capacity installed in 2013. Presently, renewable power capacity exceeds 190 GW, biofuels are responsible for roughly 10% of our nation's fuel supply, and renewable thermal energy systems heat and cool a growing number of homes, businesses, public buildings, and other structures throughout the country. The array of technologies are either fully or increasingly cost-competitive with conventional energy sources, and costs continue to fall. Per Bloomberg New Energy Finance, private-sector investment in the U.S. clean energy sector surpassed $100 billion in 2012–2013, stimulating economic development while supporting hundreds of thousands of jobs. The industry-specific authors of the *Outlook* forecast this growth to continue, driven by increasing cost-competitiveness with conventional generation, technology advancements, and growing acceptance by Americans to embrace clean and renewable technologies.

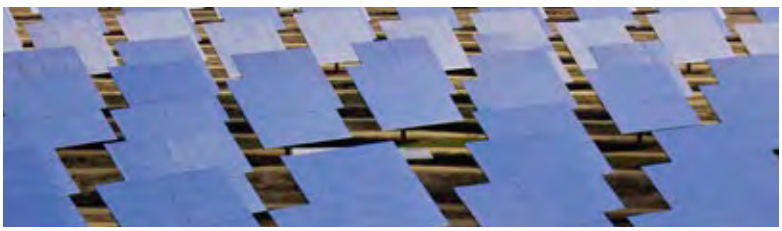
The impressive growth of renewable energy over the past decade is a signal that, when certain, state and federal policies have worked. Further scale up requires evolving and cost-effective policies that drive continued private-sector investment. ACORE offers the following, high-level recommendations for growth:

- Building on the success of past and present policy efforts, reinvigorate effective policies to promote market certainty, stable growth, and align federal, state, and private initiatives.
- Increase access to greater amounts of cheaper and more liquid capital by extending to renewable energy innovative financing options that are successful in motivating capital formation in other sectors.
- Promote the expansion of all proven forms of renewable energy, whether centralized or distributed power generation, transportation fuels, thermal energy, or other technologies. America needs a diverse array of options to transform its energy sector to meet 21st century needs.

- Continue support of public and private research, development, demonstration, and deployment to fuel the next generation of renewable technologies.
- Build renewable energy in tandem with enabling technologies, such as energy storage, hydrogen fuel cells, waste heat, and smart grid technologies, to enhance system effectiveness.

A number of opportunities exist at the federal, state, and local levels for industry advancement and investment; however, they are not one-size-fit-all solutions for every renewable technology. The articles in this report detail specific market drivers for the biofuel, biomass, geothermal, hydropower, solar, waste, and wind energy sectors. We applaud the unity of the renewable industry community and their united front demonstrated in *The Outlook for Renewable Energy in America: 2014*.

With the right policy mechanisms in place, the potential of America's clean energy economy extends beyond one fuel choice or pipeline, and provides the country with an unparalleled opportunity to reinvigorate our economy while protecting our environment. An America powered on renewable power, fuels, and thermal energy is a stronger, more secure, prosperous and cleaner America.



The Outlook for

WIND POWER

The American investment in wind energy continues to pay off in the form of reduced costs, improved efficiency, and lower prices for consumers. The beginning of 2014 marked a record wave of new construction, and the American Wind Energy Association reported that wind power continues to lead the way on affordable, reliable renewable energy.

Tom Kiernan
CEO, AWEA

"In many parts of the country today[...] wind is the most economic form of new energy generation," as NextEra Energy Chief Financial Officer Moray P. Dewhurst said on a recent earnings call.

Investments in technological advancements and stable policy have helped drive down the cost of wind energy by 43% in four years, and the industry remains on schedule to grow to supply 20% of the U.S. power grid by 2030, and beyond.

WIND POWERS OVER 4% OF U.S. GRID IN 2013

Net generation by wind energy at the start of 2014 was up 19% from the year before, bringing American wind power to 4.13% of U.S. electricity generation overall. At the state level, Iowa took the prize for largest percentage of its electricity generated from wind in 2013, at 27.38%. South Dakota finished second with 25.95%, followed by Kansas with 19.39%.

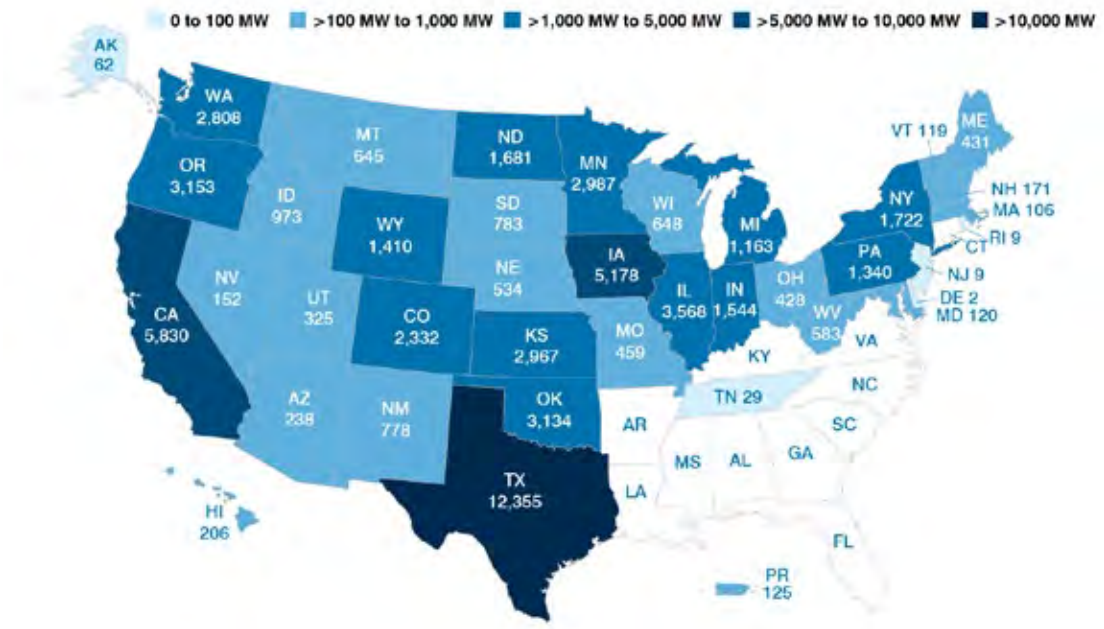
Those numbers have the chance to keep growing. As 2014 began, there were more U.S. wind power megawatts (MW) under construction than ever before in history: more than 10,900 MW started construction activity during the fourth quarter, and more than 12,000 MW are currently under construction. When completed, these 90+ projects will generate enough electricity to power an additional 3.5 million households.

On-shore projects are currently under construction in at least 20 states. There are more than 7,000 MW under construction in Texas alone—more megawatts than any other state currently has installed. Iowa has the second most megawatts under construction (1,050 MW). Other top states for construction activity include Kansas (722 MW), North Dakota (632 MW), Michigan (342 MW), and New Mexico (317 MW).

2013 was also important to the budding offshore wind industry in the United States. The University of Maine's DeepCwind Consortium deployed a quarter-scale, floating turbine in a pilot project. In addition, the U.S. Department of the Interior (DOI) held auctions for areas off Rhode Island, Massachusetts and Virginia, while Maryland passed legislation to support 200 MW of offshore wind power, and the U.S. Department of Energy (DOE) continued work on seven innovative demonstration projects.

While the impressive number of new construction projects is excellent news for the industry, the unpredictability of the federal production tax credit (PTC) in Congress is still forcing the industry into a boom-bust cycle.

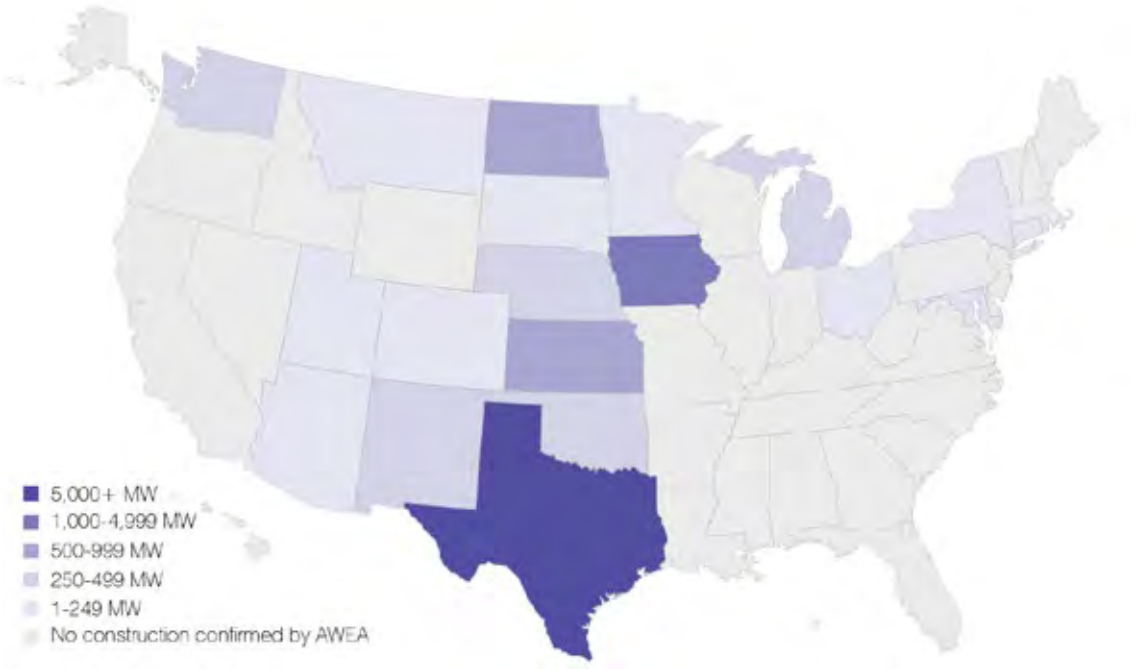
U.S. wind power capacity installations by state, 4Q 2013



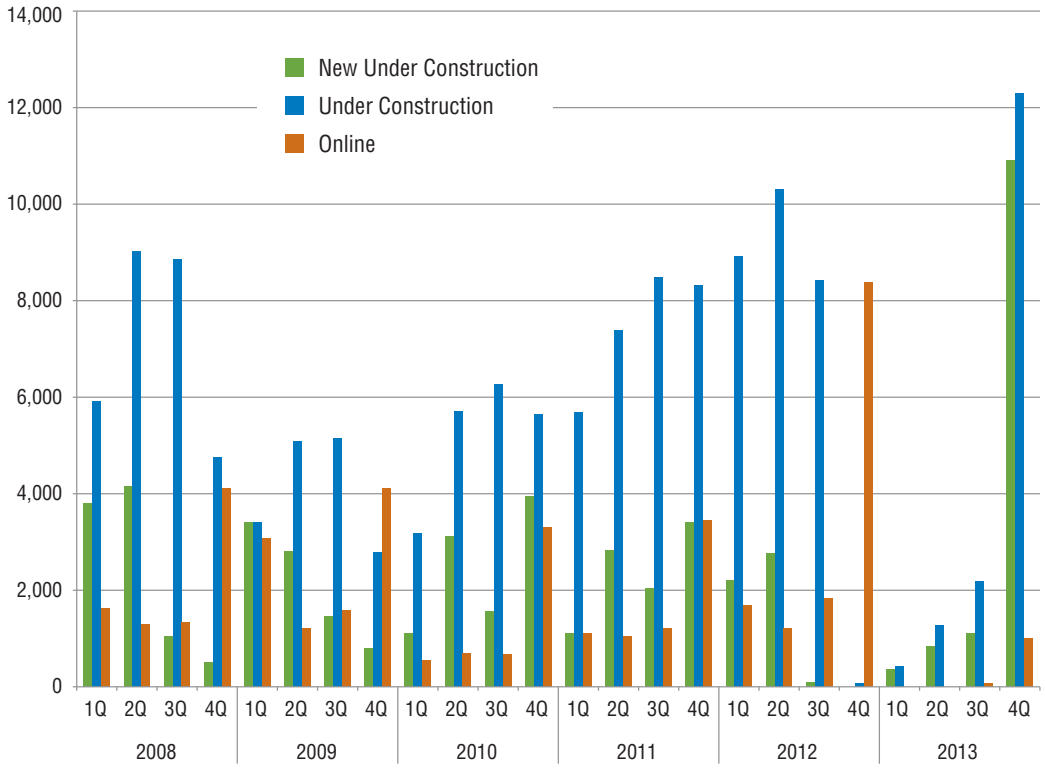
Following the late extension of the PTC and investment tax credit (ITC) on January 2, 2013, coupled with the rush to build projects in the fourth quarter of 2012 that spurred a historic number of installations, the U.S. wind industry installed 1.6 MW of new capacity during the first quarter of 2013 and 0 MW the second quarter. In the third quarter, the U.S. installed 68.3 MW through the completion of projects in Alaska, California, and Colorado.

The fourth quarter of 2013 saw the most activity with 1,012.4 MW completed across Kansas, California, Michigan, Texas, New York, Nebraska, Iowa, Colorado, Massachusetts, and Indiana.

Wind power capacity under construction, 4Q 2013



Completed and under construction wind power capacity, 2008–2013



Total wind power capacity installations for 2013 were 1,084 MW. This represents a 92% reduction from the record-setting 13,131 MW installed during 2012. This drop-off can be attributed to the late extension of the PTC and ITC in January 2013.

Despite the effects of the PTC's expiration, wind power's growth in 2013 was significant: there are now 61,108 MW of installed wind capacity in the U.S., enough to power over 15.3 million homes.

Of the projects under construction, at least 3,770 MW of wind energy projects have long-term power offtake agreements in place through long-term power purchase agreements (PPAs) or direct utility ownership. A large percentage of projects under construction in Texas are merchant capacity on ERCOT, the state's main grid operator, which as of this year is 10% wind-powered. Additional wind energy capacity has secured long-term power offtake agreements but has not yet started construction.

Construction in 2014 is focused primarily in the interior region, from North Dakota down through Texas. The late 2013 completion of the competitive renewable energy zone (CREZ) transmission lines in the Panhandle and Western parts of Texas has spurred wind

development in the state. According to ERCOT, 6,947 MW of proposed projects have signed interconnection agreements and a total of 24,000 MW of proposed wind projects have applied to connect to the ERCOT grid. The response to the opening of such high-quality wind resource has been so overwhelming that even though the CREZ grid upgrades were just completed, the grid operator is already exploring additional transmission expansions to facilitate more wind energy development in the Panhandle.

COST AND CONSUMER BENEFITS

Wind turbine prices and wind energy costs have dropped sharply in recent years. Technological improvements are rapidly making wind turbines more productive and reducing costs, while expanded U.S. manufacturing is achieving economies of scale and reducing transportation costs that can be up to a fifth of the cost of a wind farm. As mentioned, the DOE *Wind Technologies Market Report 2012* confirms that the cost of wind energy has declined by 43% over the last four years.

As the report explains:

1. The capital cost to develop wind power continues to drop
2. The average cost to purchase electricity provided by wind is falling
3. The productivity of wind turbines continues to increase
4. 70% of the value of wind turbines installed in the U.S. now carries a "Made-in-the-USA" label

Zero-fuel-cost wind energy directly displaces the output of the most expensive and least efficient power plants currently operating. Power plant rank order is based on the cost of producing an incremental amount of electricity, so only fuel costs and variable operations and maintenance costs are considered. As a result, wind energy and other zero-fuel-cost resources are always used first, and they displace the most expensive power plant that otherwise would have operated. Because that is almost always the least efficient fossil-fired power plant, adding wind energy significantly reduces fossil fuel energy costs, as well as pollution.

Significant water savings come along with those for fuel. In 2013, wind power saved 36.5 billion gallons of water. Not only does wind conserve water for other valuable uses, but it is a “drought-resistant cash crop,” providing consistent income for farmers and ranchers who host turbines on their land.

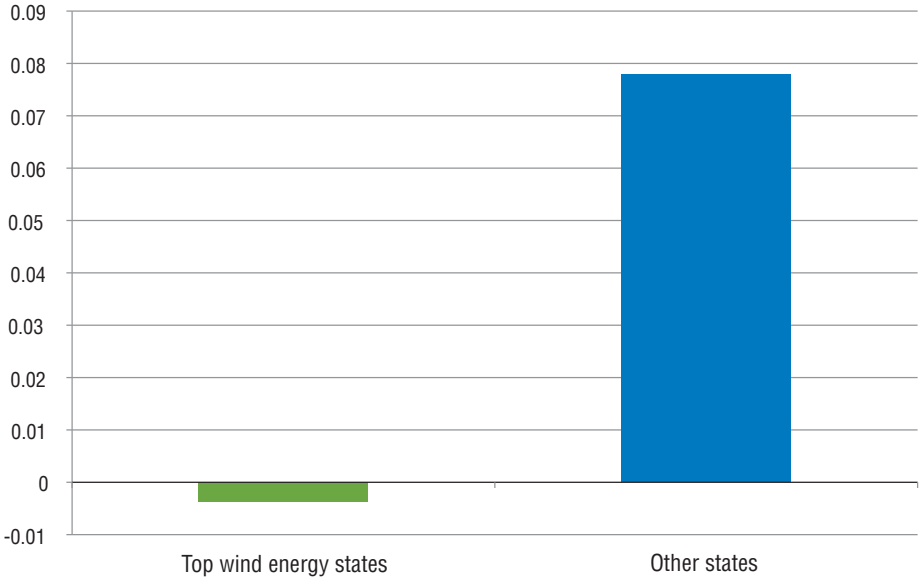
More than a dozen studies conducted by independent grid operators, state governments, academic experts, and others have found that wind energy benefits consumers by reducing electricity prices, and utilities are taking note:

"Wind prices are extremely competitive right now, offering lower costs than other possible resources, like natural gas plants." David Sparby, President and CEO of Xcel Energy's Northern States Power, announcing 600 MW of new wind power contracts in 2013.

"The expansion is planned to be built at no net cost to the company's customers and will help stabilize electric rates over the long term by providing a rate reduction totaling $10 million per year by 2017, commencing with a $3.3 million reduction in 2015." MidAmerican Energy Co., 2013 press release, after the Iowa Utilities Board approved the addition of 1,050 MW of wind generation in Iowa.

Cost savings with wind power are apparent across the country. Newly released DOE data shows that consumers in the states that use the most wind energy have fared far better than consumers in states that use less wind energy.

Electricity price changes, wind-heavy states versus least wind-heavy states



The 11 states that produce more than 7% of their electricity from wind energy have seen their electricity prices fall by 0.37% over the last five years, while all other states have seen their electricity prices increase by 7.79% over that period. This is clear evidence for wind energy's impact on keeping consumers' electricity prices down.

POLICY CERTAINTY AND OUTLOOK

To keep growing and providing clean, affordable electricity to ratepayers, the wind power industry must have a greater degree of policy certainty.

The PTC, as a performance-based incentive, has been a tremendous success.

With this credit in place, the U.S. wind industry was the number one source of new electricity generation capacity in 2012. In addition to bringing electricity to 15 million American homes, the PTC attracted $25 billion of private investment in the U.S. economy in just one year — which is 17 times the current annual value of the tax credit. Without it, this level of private investment in the U.S. simply would not have occurred.

That investment means jobs in construction and manufacturing, federal, state, and local tax payments by the resulting wind farms and factories that more than repay the up-front tax relief, as well as lower electric rates.

Historically when the PTC has been allowed to expire, the U.S. industry has faced a 70-95% drop-off in installations; in 2013, that drop-off amounted to a 92% reduction in new wind generating capacity brought online.

A poll conducted by USA TODAY in December 2013 suggested Americans are reacting to the impacts of climate change and understand renewable energy's role in mitigating those effects. Of those surveyed, 73% supported continued tax incentives for wind, solar, and hydropower.

Policy stability is critical to continuing this story for American manufacturing and wind energy development. The industry needs the PTC extended for the longest practical term to provide our businesses the ability to plan and invest in further improvements in wind technology, investments which will continue to bring consumer costs down.

ABOUT THE AMERICAN WIND ENERGY ASSOCIATION

AWEA is the national trade association of the U.S. wind energy industry, with 1,300 member companies, including global leaders in wind power and energy development, wind turbine manufacturing, component and service suppliers, and the world's largest wind power trade show, the AWEA WINDPOWER Conference & Exhibition, which takes place next in Las Vegas, May 5-8, 2014. AWEA is the voice of wind energy in the U.S., promoting renewable energy to power a cleaner, stronger America.

Renewable Energy in the 50 States:
Midwestern Region

ACORE
American Council On Renewable Energy

2013 Edition

About ACORE

ACORE, a 501(c)(3) non-profit membership organization, is dedicated to building a secure and prosperous America with clean, renewable energy. ACORE seeks to advance renewable energy through finance, policy, technology, and market development and is concentrating its member focus in 2013 on National Defense & Security, Power Generation & Infrastructure, and Transportation. Additional information is available at www.acore.org.

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Cover photo of Missouri River Garrison (bottom left) by North Dakota National Guard.

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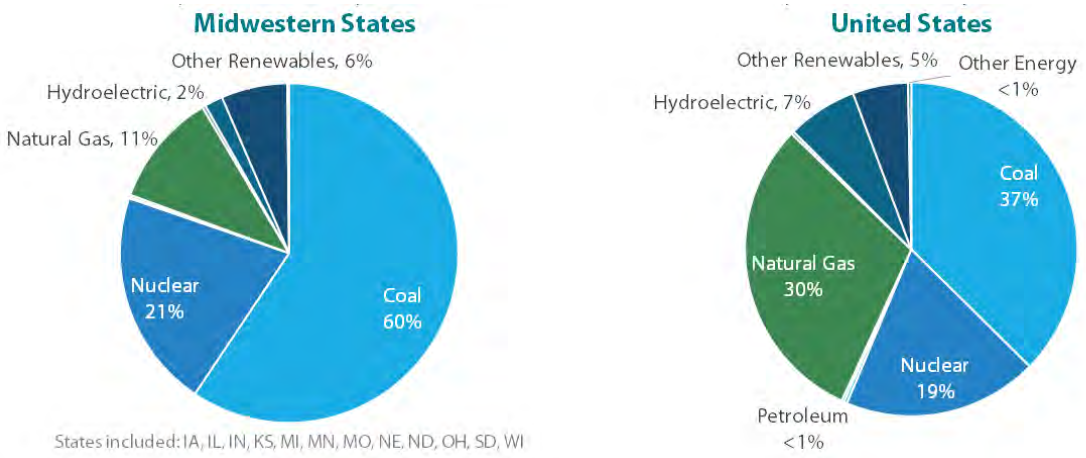
Executive Summary

The Midwest's remarkable renewable energy resources, vast agricultural land, strong manufacturing base, and leading research institutions have propelled the region to become a hub for renewable energy development. It is home to over a third of U.S. wind power capacity and 80% of U.S. biofuel production capacity. However, uncertainty about federal policy – like the production tax credit (PTC) and renewable fuels standard (RFS) – as well as transmission constraints could hinder Midwestern renewable energy capacity additions in the near term, with 2013 expected to yield only a fraction of the installations seen in previous years. Nevertheless, increasingly affordable project costs and state renewable energy targets will continue to drive market momentum in the region, as indicated by recent, positive signals given by renewable energy companies and utilities.

Electricity Generation by Source, 2012:



Source: EIA

While coal dominates the Midwest's power supply, the states recognize the importance of renewable energy and have set targets for its use and deployment. Out of the 12 states profiled in this report, eight have binding standards for renewable and/or clean energy and three have non-binding goals. A number of the states support these targets through an array of financial incentives for wind power, on-farm energy, biofuels, solar power, and other renewable energy systems.

The cost of building renewable energy projects continues to decline in many Midwestern states, facilitated by the region's nationally recognized wind and bioenergy resources.[1] As a result, two of Michigan's largest utilities recently eliminated a surcharge on their customers' bills originally designed to cover the cost of meeting the state's renewable portfolio standard, indicating that renewable energy projects are costing them less than expected.[2] In addition, a major investor-owned utility recently chose wind power as its technology of choice because of its "lower costs than other possible resources," in its announcement to build four new power projects in the Midwest. These four projects would add 600 MW of wind energy capacity to the grid and power up to 750,000 homes.[3]

Home to the Corn Belt and much of the nation's agricultural activity, nine of the top ten biofuel states by production capacity are located in the Midwest. Companies and universities spearhead advanced biofuel

[1] http://www.awea.org/Resources/Content.aspx?ItemNumber=5547#CostofWindEnergy
[2] http://www.greentechmedia.com/articles/read/in-michigan-renewables-costing-utilities-less-than-expected
[3] http://thinkprogress.org/climate/2013/08/24/2520551/upper-midwest-windfarm

research in Midwestern states, with numerous pilot and small-scale facilities that develop cellulosic and algae-sourced fuels, and development is underway on the first facilities that will produce advanced biofuels at commercial scale. Airlines and the U.S. military also see the region as a proving ground for aviation fuels. Major airlines work with biofuel companies and research institutions to grow feedstocks for and produce renewable jet fuel in the Midwest, with plans to launch biofuel-powered planes from Midwestern airports.[4] In May 2013, the U.S. Department of Defense chose Nebraska to be the location of a biofuel plant that will sustainably power jets and ships by 2016. Nevertheless, the continued growth of and investment in renewable fuels in the Midwest is in question if the federal RFS is scaled back or repealed.

Over a third of U.S. wind capacity is located in the Midwest. Five Midwestern states generate over 10% of their electricity from wind energy, out of only nine states nationally. Last year resulted in a 29% increase in installed generation capacity in the Midwest, adding over 21 GW of new wind power to the grid. However, uncertainty caused by Congressional debate over the PTC, coupled with transmission constraints, have resulted in far fewer wind power facilities to be built to date in 2013.

Wind power and biofuels are far from the only renewable technologies used in the Midwest:

- Solar power saw a 150% boost in capacity in 2012, with 200 MW now connected to the grid in Midwestern states. Policies that encourage distributed generation, like net metering, also spur the growth of residential and commercial solar energy markets in states such as Wisconsin and Missouri.
- Many states use their considerable agricultural and other biomass resources, like corn stover, to produce bioenergy. The Midwest's numerous dairy farms, wastewater treatment plants, and other facilities produce biogas for electricity, heat, and fuel, helping to reduce air and water pollution.[5]
- Waste-to-energy projects in several states convert municipal solid waste into electricity and/or steam for use as an energy source for municipalities and private industry.
- Renewable heating technologies, like biomass thermal, geothermal heat pumps, and solar thermal, can be used to offset the region's reliance on imported fossil fuels for heating purposes.[6] Waste heat to power technologies capture heat from industrial processes to produce electricity, and are considered renewable in at least six Midwestern states.[7]
- Hydropower is an important energy resource in some Midwestern states, responsible for 49% of electricity generation in South Dakota.

Despite the industry's recent growth, electricity transmission inadequacies stifle large-scale development so that many states tap into only a fraction of their available resources.[8] New transmission line proposals in Illinois, Iowa, Michigan, Missouri, Nebraska, and North Dakota could help to open bottlenecks and encourage continued renewable energy development.

The importance of renewable energy in the Midwest will continue to grow as it becomes an increasingly competitive alternative to fossil fuel generation.

[4] http://www.midwestenergynews.com/2013/07/01/midwest-seen-as-proving-ground-for-biofuel-powered-airliners
[5] http://www.gpisd.net/vertical/Sites/%7B1510F0B9-E3E3-419B-AE3B-582B8097D492%7D/uploads/%7B6DEFD5AC-B930-4ED1-AB05-0AD7EB86EA6B%7D.PDF
[6] http://heatingthemidwest.org/wp-content/uploads//MidwestVision_Final_04212013.pdf
[7] http://www.heatispower.org/wp-content/uploads/2013/06/WHP-Fact-Sheet-6-10-2013.pdf
[8] http://www.bendbulletin.com/apps/pbcs.dll/article?AID=/20130806/NEWS0107/308060335/1254

Midwestern State Installed Capacity Rankings:

	Renewable Power (w/hydro)	Renewable Power (w/o hydro)	Renewable Fuels
1.	**Iowa***: 5,280 MW	**Iowa***: 5,149 MW	**Iowa**: 4,153 mGy
2.	**Illinois***: 3,799 MW	**Illinois***: 3,759 MW	**Nebraska**: 2,063 mGy
3.	**Minnesota***: 3,693 MW	**Minnesota***: 3,489 MW	**Illinois**: 1,586 mGy
4.	**Kansas***: 2,728 MW	**Kansas***: 2,721 MW	**Indiana**: 1,254 mGy
5.	**South Dakota†**: 2,381 MW	**North Dakota†**: 1,690 MW	**Minnesota**: 1,213 mGy
6.	**North Dakota†**: 2,304 MW	**Indiana†**: 1,611 MW	**South Dakota**: 1,023 mGy
7.	**Michigan***: 1,866 MW	**Michigan***: 1,496 MW	**Ohio**: 670 mGy
8.	**Indiana†**: 1,702 MW	**Wisconsin***: 1,036 MW	**Wisconsin**: 537 mGy
9.	**Wisconsin***: 1,684 MW	**South Dakota†**: 783 MW	**Kansas**: 507 mGy
10.	**Missouri***: 987 MW	**Missouri***: 488 MW	**North Dakota**: 458 mGy
11.	**Ohio***: 822 MW	**Nebraska**: 471 MW	**Missouri**: 457 mGy
12.	**Nebraska**: 803 MW	**Ohio***: 394 MW	**Michigan**: 318 mGy
	Total: 28,049 MW	**Total**: 23,087 MW	**Total**: 14,239 mGy

*=State has a renewable portfolio standard
†=State has a non-binding renewable portfolio goal
MW=megawatt; mGy=million gallons per year
Sources: See User's Guide

Renewable Energy in Illinois

Summary

Illinois is one of the top electricity-generating states in the country and a leading net exporter of electricity to other states. Its extensive wind and biomass resources and renewable portfolio standard, which includes carve-outs for solar energy and distributed generation, foster a supportive environment for its citizens and the commercial, industrial, and utility sectors to invest in renewable energy. The state ranks second in the Midwest for installed renewable power capacity and third in the region for biofuels production capacity.

Installed Renewable Energy Capacity, 2012			
Wind Power	3,568 MW	Marine Power	0 MW
Solar Photovoltaic	42.9 MW	Biomass & Waste	148.6 MW
Solar Thermal Electric	0 MW	Ethanol	1,412 mGy
Geothermal Power	0 MW	Biodiesel	173.6 mGy
Hydropower	39.7 MW	**Totals**	3,799 MW; 1,586 mGy

Sources: See User's Guide for details

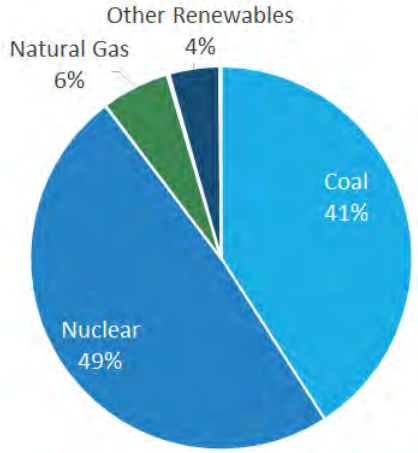
Market Spotlight

- Illinois is a national leader in the wind energy supply chain, ranking fourth among states for installed wind power capacity. In December 2012, three wind farms commissioned in Vermillion and Champaign, Woodford, and Henry Counties added an additional 500 MW to the grid.
- The state ranks third in the nation for ethanol production capacity and fourth for biodiesel production capacity. Advanced biofuel facilities in the state produce cellulosic ethanol and biodiesel from woodchips and agricultural residues.
- A proposed 400 mile, $1.1 billion transmission line stretching across the state received approval from the Illinois Commerce Commission in summer 2013. Construction is expected to begin in 2014, providing a significant boost to the economy while connecting thousands of residents to clean sources of energy.
- Phase I of a planned 62 MW solar PV farm in Rockford came online in October 2012. When fully operational, the facility will be one of the largest of its kind in the Midwest.

Economic Development

Employment	**2011**	
Green Goods & Services Jobs	136,447	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	$1.45bn	$817m
Venture Capital & Private Equity	$50.8m	$121.5m

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

Renewable Energy in Illinois

State Policy

Renewable Portfolio Standard	▸ 25% by compliance year 2025-2026 ▸ Investor-owned utilities (IOUs) and retail suppliers (covering 89% of state's electric load) ▸ Technology minimums – *wind*: 75% of annual requirement for IOUs, 60% for alternative retail electric suppliers; *PV*: 60% of annual requirement in 2015-2016 and after; *distributed generation:* 1% of annual requirement in 2015-2016 and after for IOUs ▸ Bundled renewable energy credits (RECs) and tradable RECs may be used for compliance ▸ Procurement is limited to "cost-effective" resources
Net Metering	▸ IOUs, alternative retail electric suppliers ▸ System capacity limit – *current rules:* 40 kW; *new rules*: 2 MW ▸ Aggregate capacity limit – *current*: 1% of utility's peak demand in previous year; *new rules*: 5% of utility's peak demand in previous year ▸ Net excess generation – *current*: credited to customer's next bill at retail rate, granted to utility at end of 12 months; *new rules*: only for non-competitive customers; non-hourly customers keep existing rules; hourly customers receive energy credit and delivery service credit based on hourly rate ▸ Customer owns RECs; virtual net metering allowed
Interconnection Standards	▸ IOUs ▸ External connect switch required ▸ Insurance requirements vary by system size/type
Tax Incentives	**Sales Tax Exception:** ▸ For businesses building a new wind power facility in an "Enterprise Zone" ▸ Exemption from the full state sales tax and any additional local state sales taxes for building materials incorporated into the facility ▸ Must involve a minimum investment of $12m and create 500 full-time jobs
Public Benefit Fund	▸ Supports renewables through grants, loans, and other incentives ▸ Total fund: ~$100m (1998-2015)
Rebates and Grants	**Solar and Wind Energy Rebate Program:** ▸ Maximum incentive – *residential*: $10,000; *commercial*: $20,000; *nonprofits and government sector*: $30,000 ▸ System size – *PV*: ≥1 kW; *solar thermal*: 0.5 therms/day or 60 sq. ft.; *wind*: 1-100 kW **Community Solar and Wind Grant Program:** ▸ *Businesses*: up to 30% of project costs for solar thermal and wind and 25% for solar PV; *government and nonprofits*: 40% of project costs ▸ Maximum incentive of $250,000 **Biofuels Production Facility Grants:** ▸ Construction or expansion of biodiesel or ethanol facilities ▸ The lesser of 10% of the total construction costs of the facility or $4m **Alternative Fuel Vehicle (AFV) and Alternative Fuel Rebates:** ▸ Rebate for 80%, up to $4,000, of the incremental cost of purchasing an AFV ▸ 80%, up to $4,000, of the cost of converting a vehicle to an AFV, and the incremental cost of purchasing alternative fuels
Bonds	▸ The Illinois Finance Authority issues tax-exempt bonds for eligible renewable energy projects that provide a significant public benefit to the state
More Info	▸ DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=IL ▸ Illinois Commerce Commission (RPS): www.icc.illinois.gov/electricity/procurementprocess2013.aspx ▸ Illinois Energy Office (Energy): http://www.ildceo.net/dceo/Bureaus/Energy_Recycling ▸ Illinois Finance Authority (Energy): http://www.il-fa.com/programs/energy

Renewable Energy in Indiana

Summary

Like many of its Midwestern neighbors, Indiana is endowed with plentiful wind and biomass resources, ranking fourth in the nation for ethanol production capacity and also a user of wind, wood waste, and other renewable resources for energy. In an effort to diversify its coal-heavy energy portfolio and increase in-state power generation, the state set a goal in 2011 to obtain 10% clean energy by 2025. This commitment to clean energy is expected to further encourage the sector's growth, but perhaps not at the rate of neighboring states that have more aggressive policies and similar renewable resources.

Installed Renewable Energy Capacity, 2012			
Wind Power	1,543 MW	Marine Power	0 MW
Solar Photovoltaic	4.4 MW	Biomass & Waste	62.3 MW
Solar Thermal Electric	0 MW	Ethanol	1,148 mGy
Geothermal Power	0 MW	Biodiesel	106 mGy
Hydropower	92.1 MW	**Totals**	1,702 MW; 1,254 mGy

Sources: See User's Guide for details

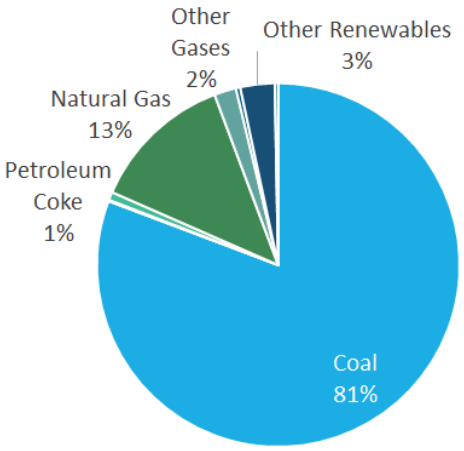
Market Spotlight

- The 200 MW Wildcat Wind Farm in Tipton and Madison Counties began operations in December 2012, sited on land that also continues to be used for corn, soybean, and tomato farming.
- The Indianapolis International Airport installed the first phase of the nation's largest airport-sited solar farm in September 2013. Phase II began construction in the same month, and the project will total 25 MW in capacity when complete – to be one of the largest solar power facilities in the region.
- About 30% of Indiana's installed ethanol capacity was not operational in 2012. In March 2013, commercial operations resumed at a Linden bioethanol plant after idling for about five months. The facility will once again generate 110 million gallons per year of bioethanol and 315,000 tons of dry distillers grains.
- A new biogas upgrading facility at Fair Oaks Farm became operational in March 2012, which converts biogas from cow manure into the equivalent of nearly 10,000 gallons per day of diesel fuel. This fuels a fleet of 42 milk trucks. The project is expected to reduce greenhouse gas emissions of the fleet by roughly 40,000 tons per year.

Economic Development

Employment	**2011**	
Green Goods & Services Jobs	70,156	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	$1.3m	$280m
Venture Capital & Private Equity	-	-

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

Renewable Energy in Indiana

State Policy

Clean Energy Portfolio Goal	▸ 10% by 2025 (voluntary) ▸ Only public utilities may participate ▸ Up to 30% of goal may be met with clean coal, nuclear, CHP, natural gas, and net-metered distributed generation systems ▸ 50% of qualifying energy must come from within the state ▸ Thermal energy used for heating, cooling or mechanical work is also eligible
Net Metering	▸ Investor-owned utilities (IOUs) ▸ System capacity limit: 1 MW ▸ Aggregate capacity limit: 1% of utility's most recent peak summer load ▸ Net excess generation credited to customer's next bill at retail rate, carries over indefinitely
Interconnection Standards	▸ IOUs, regulated municipal utilities, regulated electric cooperatives ▸ No system capacity limit specified
Tax Incentives	**Property Tax Incentive:** ▸ Solar, wind, hydropower and geothermal systems and their affiliated equipment (including storage and distribution equipment) are exempt from property tax ▸ For real property and mobile homes equipped with renewable energy systems **Income Tax Deduction**: 50% of the cost of materials and installation labor for solar-powered roof fans, up to $1,000 **Sales and Use Tax Exemption:** Certain wind turbine components are exempt from the state sales and use tax **Alternative Fuel Vehicle (AFV) Manufacturer Tax Credit:** ▸ 15% of qualified investments for the manufacture or assembly of AFVs ▸ Facility must agree to maintain operations for at least 10 years, and employees must be paid 150% of the state's hourly minimum wage **Ethanol Production Tax Credit:** ▸ $0.125/gallon of ethanol produced, including cellulosic ethanol ▸ Unused credit may be carried forward to the following taxable years ▸ Maximum credits per taxpayer: $2m for grain ethanol facilities that produce 40-60 mGy; $3m for grain ethanol facilities that produce at least 60 mGy; and $20m for cellulosic facilities that produce at least 20 mGy **Biodiesel Production Tax Credit:** ▸ $1.00/gallon of biodiesel produced and used in biodiesel blends ▸ Single taxpayers may receive no more than $3m total for all taxable years **Biodiesel Blending Tax Credit:** ▸ $0.02/gallon of blended biodiesel ▸ Single taxpayers may receive no more than $3m total for all taxable years
Grants	**Community Conservation Challenge** ▸ $25,000-$150,000 for community energy conservation projects ▸ Applies to alternative fuel vehicle fleets, CHP, biomass, energy efficiency, solar, traffic signal retrofits, waste management and recycling, and wind energy projects
More Info	▸ DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=IN ▸ Office of Energy Development: www.in.gov/oed/2649.htm ▸ Utility Regulatory Commission: www.in.gov/iurc ▸ Fuel and Environmental Tax Forms: www.in.gov/dor/3512.htm

Renewable Energy in Iowa

Summary

Iowa has experienced significant renewable energy growth in recent years, a leading state in the production of renewable energy from wind, ethanol, and biodiesel, and ranking first in the Midwest for renewable power and fuels production capacity. The state's strong manufacturing and agricultural sectors coupled with its early policy support create an attractive environment for companies and individuals interested in producing renewable energy in the state. With the Iowa Utilities Board recently approving over 1 GW of additional wind generation by the end of 2015, the climate for wind energy development in the state is promising.

Installed Renewable Energy Capacity, 2012			
Wind Power	5,133 MW	Marine Power	0 MW
Solar Photovoltaic	1.2 MW	Biomass & Waste	14.6 MW
Solar Thermal Electric	0 MW	Ethanol	3,848 mGy
Geothermal Power	0 MW	Biodiesel	304.5 mGy
Hydropower	131.3 MW	**Totals**	5,280 MW; 4,153 mGy

Sources: See User's Guide for details

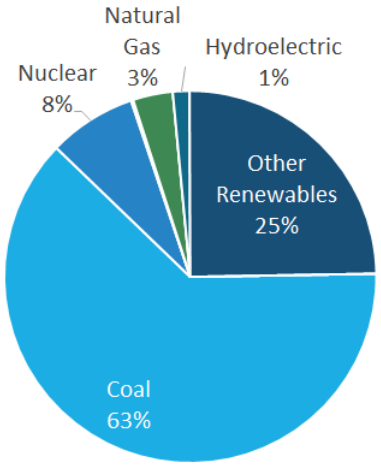
Market Spotlight

- In 2012, Iowa ranked third in the nation for installed wind power capacity, with 24.5% of total generated electricity coming from wind power, more than any other state. An additional four wind farms came online in December 2012, adding 500 MW of wind generating capacity to the state's power portfolio.
- The state is home to over a quarter of U.S. ethanol production capacity and is a major producer of U.S. biodiesel. Biodiesel production reached a record high in Q2 2013, when the state's nine plants produced nearly 57 million gallons of biodiesel in three months.
- Iowa recently phased out non-ethanol unleaded gasoline in place of ethanol-blended 87 octane gas. E15 ethanol blends are expected to become the lowest-cost registered fuel in the state.[9]
- A $250 million cellulosic ethanol plant in Emmetsburg is expected to begin production early next year, which will be one of the first sites to turn corn husks and other crop waste into fuel at a commercial volume.
- Two waste-to-energy facilities are planned in the state that will convert municipal solid waste into feedstocks for the production of compressed biogas and cellulosic ethanol.

Economic Development

Employment	2011	
Green Goods & Services Jobs	43,791	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	$864.7m	$1.24bn
Venture Capital & Private Equity	-	-

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

[9] http://farmprogress.com/story-e15-ethanol-blend-expected-lowest-cost-fuel-iowa-9-101034

Renewable Energy in Iowa

State Policy

Alternative Energy Law	▸ Investor-owned utilities (IOUs) must own or contract a combined total of 105 MW of renewable generating capacity ▸ Qualifying systems include solar, wind, waste management, resource recovery, refuse-derived fuel, agricultural crops or residues, wood-burning facilities, and small hydropower
Net Metering	▸ IOUs ▸ System capacity limit of 500 kW; no aggregate limit specified ▸ Net excess generation credited to customer's next bill at retail rate, carries over indefinitely
Interconnection Standards	▸ IOUs, Linn County REC ▸ 10 MW limit on system capacity ▸ Insurance requirements vary by system size and/or type
Loans	**Alternative Energy Revolving Loan Program:** ▸ 50% of financed project costs ▸ Maximum incentive of $1,000,000 for most applicants; $500,000 for non-rate regulated gas and electric utilities ▸ No interest; maximum term of 20 years **IADG Energy Bank Revolving Loan Program:** ▸ $50,000-$500,000 for commercial and industrial renewable energy projects ▸ ≥1% interest rate; loan term of up to 10 years; 1% origination fee **Iowa Energy Bank:** ▸ Renewable energy systems at schools and colleges, hospitals, and governments ▸ ≥1% interest rate; 15-year repayment period; 0.25% servicing fee; 2% origination fee
Tax Incentives	**Renewable Energy Production Tax Credits** *(Personal or Corporate)*: ▸ 1 cent/kWh for energy sold or generated for on-site consumption by eligible wind energy facilities; maximum total eligibility of 50 MW ▸ 1.5 cents/kWh for energy sold by eligible facilities and/or used onsite by facilities 750 kW and larger; maximum total eligibility for wind is 363 MW and for non-wind is 53 MW **Solar Energy Systems Tax Credit** *(Personal or Corporate)*: 15% credit; maximum incentive $3,000 for residential and $15,000 for commercial; budget of $1,500,000/year **Renewable Energy Equipment Exemption:** Sales tax exemption for solar, wind, and hydropower equipment **Property Tax Exemption:** The market value added to a property by a solar or wind energy system is exempt from the state's property tax for five full assessment years **Methane Gas Conversion Property Tax Exemption:** For the real and personal property for methane gas conversion facilities operated in connection or conjunction with publicly-owned sanitary landfills **Geothermal Tax Credit:** Tax credit equal to 20% of the federal tax credit for geothermal heat pumps; excess credit may be carried forward 10 years **Energy Replacement Generation Tax Exemption:** Replacement generation tax of 0.06 cents/kWh in place of a property tax on generation facilities; applies to landfill gas, wind, hydropower, and self-generators **Biodiesel Producer Tax Refund:** Refund of sales or use taxes paid on purchases, 2 cents/gallon in 2014
More Info	▸ DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=IA ▸ Iowa Utilities Board: www.state.ia.us/iub ▸ Iowa Economic Development: www.iowaeconomicdevelopment.com/Programs/Energy ▸ Department of Revenue: www.iowa.gov/tax/index.html

Renewable Energy in Kansas

Summary

Kansas has one of the most promising wind resource potentials in the country and more than doubled its wind power generating capacity in 2012, raising its ranking to ninth in the nation for wind power installations. The state ranks within the top ten states nationally for ethanol production capacity. Its 20% renewable portfolio standard (RPS) and financial incentives promote large and small-scale renewable energy generation, and three out of six utility companies have already met their RPS requirements seven years ahead of schedule.[10] However, the shortage of high-voltage power lines to connect remote areas to population centers could slow the future development of renewable energy projects in the state.

Installed Renewable Energy Capacity, 2012			
Wind Power	2,713 MW	Marine Power	0 MW
Solar Photovoltaic	0.5 MW	Biomass & Waste	7.2 MW
Solar Thermal Electric	0 MW	Ethanol	503.5 mGy
Geothermal Power	0 MW	Biodiesel	3.9 mGy
Hydropower	7 MW	**Totals**	2,728 MW; 507 mGy

Sources: See User's Guide for details

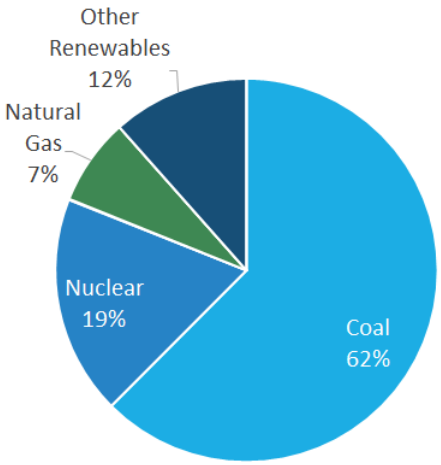
Market Spotlight

- Kansas was among the country's largest and fastest growing wind energy markets in 2012. Construction on the second phase of the Flat Ridge Wind Farm completed at the end of 2012, adding 419 MW to the grid and creating 30 permanent jobs. In spring 2013, the 250 MW Buffalo Dunes wind farm broke ground and is expected to be commissioned by the end of the year.
- Development continues in Hugoton on one of the nation's first commercial cellulosic ethanol plants, which will use agricultural waste, non-feed energy crops, and wood waste to produce fuel as well as electricity. The 25 million gallon facility secured a $132.4 million loan guarantee from the Department of Energy in fall 2011, and developers expect to commence ethanol and power production in early 2014. The plant will create 65 permanent jobs.
- A 359,000 square foot retail store under construction in Merriam will be heated by the largest geothermal heating-and-cooling system in Kansas.

Economic Development

Employment	**2011**	
Green Goods & Services Jobs	25,632	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	$1.48bn	$2.09bn
Venture Capital & Private Equity	$2.5m	-

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

[10] http://www.nrdc.org/energy/renewable-portfolio-standards/files/RPS-KS-rebuttal-IB.pdf

Renewable Energy in Kansas

State Policy

Renewable Portfolio Standard	▸ 20% by 2020 ▸ Investor-owned utilities (IOUs) and rural electric cooperatives (representing 81.5% of the state's electric load) ▸ Unlike most other RPS policies, target is based on generation capacity rather on than retail electric sales ▸ Renewable energy credits (RECs) may only meet a portion of requirements
Net Metering	▸ IOUs ▸ System capacity limit of 200 kW for non-residential and 25 kW for residential ▸ Aggregate capacity limit of 1% of utility's retail peak demand during previous year ▸ Net excess generation credited to the customer's next bill at retail rate; granted to utility at end of the calendar year ▸ Utility owns RECs
Interconnection Standards	▸ IOUs ▸ Net metering required (same system capacity limits as net metering)
Tax Incentives	**Biofuel Blending Equipment Tax Exemption:** Property tax exemption for equipment used to store or blend petroleum-based fuel with biodiesel, ethanol, or other biofuel **Biodiesel Production Facility Tax Exemption:** ▸ Constructed or expanded biomass-to-energy facilities are exempt from state property taxes for up to 10 years ▸ Includes industrial process plants that use biomass to produce at least 500,000 gallons of cellulosic alcohol fuel, liquid or gaseous fuel, or other sources of energy, with energy content at least equal to that of 500,000 gallons of cellulosic alcohol fuel **Property Tax Exemption:** Renewable electricity systems are exempt from property taxes
Other Incentives	**Solar and Wind Manufacturing Incentive:** ▸ To support research, development, engineering or manufacturing projects ▸ Must result in at least $30m in new investment and the hiring of 200 new employees within five years ▸ Manufacturers apply for incentives through the Kansas Department of Commerce, which must request the Kansas Development Finance Authority to issue bonds to finance the project ▸ Maximum incentive of $5m **Ethanol Production Incentive:** ▸ $0.035/gallon sold to alcohol blenders ▸ Up to 15 million gallons/year for no more than seven years ▸ Only applies to grain ethanol producers who commenced production prior to July 2001 and who increased production in or after July 2001 by 5 million gallons ▸ Producers who commenced cellulosic ethanol production in or after July 2012 and who sold at least 5 million gallons also qualify ▸ As of July 2012, no new grain-based ethanol producers are eligible for the incentive **Biodiesel Production Incentive:** $0.30/gallon of biodiesel sold
More Info	▸ DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=KS ▸ Department of Commerce (Energy): www.kansascommerce.com/index.aspx?NID=135 ▸ Kansas Corporation Commission (Energy): www.kcc.state.ks.us/energy/index.htm

Renewable Energy in Michigan

Summary

A skilled workforce, supportive policies, and significant renewable energy resources have positioned Michigan to become a hub for clean energy research and production. The state is expected to reach its 10% renewable energy target by 2015, and a new report released in September 2013 suggests it could triple its wind and solar energy production to account for 30% by 2035.[11] Renewable energy is steadily becoming more cost effective in the state, and as a result, two of Michigan's largest utilities have eliminated a surcharge on customers' bills originally designed to cover the cost of meeting the state's RPS.

Installed Renewable Energy Capacity, 2012			
Wind Power	988 MW	Marine Power	0 MW
Solar Photovoltaic	19.9 MW	Biomass & Waste	488.4 MW
Solar Thermal Electric	0 MW	Ethanol	268 mGy
Geothermal Power	0 MW	Biodiesel	49.8 mGy
Hydropower	369.6 MW	**Totals**	1,866 MW; 318 mGy

Sources: See User's Guide for details

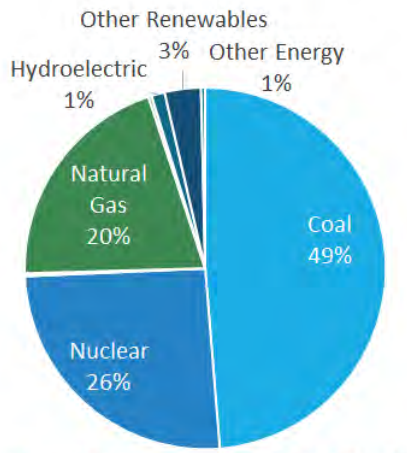
Market Spotlight

- The 120 MW Tuscola Bay Wind Project became operational in December 2012 and generates enough electricity to power more than 50,000 Michigan homes.
- An auto manufacturer has partnered with the U.S. Army to test and develop hydrogen fuel cell technology at two new facilities in the state. The partnership is expected to continue for up to five years.
- Michigan's net metering and solar pilot programs increased 55% from 2011 to 2012, to 9,583 kW of installed systems.[12]
- A research team at the University of Michigan received a $2 million federal grant to identify and test naturally diverse groups of green algae that can be used to produce biofuel.
- A 140-mile-long transmission project is currently underway in Michigan's Thumb. The project is expected to be complete by 2015, and will be capable of supporting 5,000 MW of additional wind capacity.

Economic Development

Employment	**2011**	
Green Goods & Services Jobs	82,644	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	$577.4m	$774m
Venture Capital & Private Equity	$24.4m	$1.3m

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

[11] http://www.freep.com/article/20130920/NEWS06/309200112/renewable-energy-wind-solar-Michigan-public-service
[12] http://www.smartenergyuniverse.com/regulatory/21206-michigan-electric-customers-continue-to-install-solar-and-wind-generation

Renewable Energy in Michigan

State Policy

Renewable Portfolio Standard	▸ 10% by 2015 ▸ All utilities; additional obligations for two largest investor-owned utilities: Detroit Edison (600 MW by 2015) and Consumers Energy (500 MW by 2015) ▸ May be met with bundled or unbundled renewable energy credits (RECs) ▸ Extra credits granted toward compliance for electricity from solar power, certain power produced at peak demand times, use of storage technologies, and power produced using equipment manufactured and/or from systems constructed in state
Net Metering	▸ Investor-owned utilities (IOUs), electric cooperatives, alternative electric suppliers ▸ System capacity limit of 150 kW; aggregate capacity limit of 0.75% of utility's peak load during previous year ▸ Net excess generation credited to customer's next bill at the retail rate for systems ≤20 kW or at the power supply component of the retail rate for larger systems; carries over indefinitely ▸ Customer owns RECs
Interconnection Standards	▸ IOUs, electric cooperatives ▸ Insurance requirements vary by system size and/or type
Tax Incentives	**Biomass Gasification and Methane Digester Property Tax Exemption:** Full exemption from real and personal property taxes for certain energy production-related farm facilities **Reduced Biofuels Tax:** ▸ $0.07/gallon discount on the gasoline tax for gasoline containing at least 70% ethanol ▸ $0.03/gallon discount on the diesel tax for diesel fuel containing at least 5% biodiesel **Alternative Fuel Development Property Tax Exemption:** For industrial property used for high-technology activities (including advanced vehicle technologies) or the creation or synthesis of biodiesel fuel
Loans	**Energy Revolving Loan Fund:** ▸ Farm energy and passive solar: 4% fixed interest rate; interest-only payments for first six months; six year maximum ▸ Public entity renewable energy projects: 3% fixed interest rate; six year maximum ▸ Maximum amounts – *farm energy*: $150,000; *passive solar*: $15,000; *public entities*: $2.5m
Grants	**Biomass Energy Program:** Supports biomass energy through program reports, partnerships, technical assistance, and education; funding opportunities vary annually
More Info	▸ DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=MI ▸ Michigan Energy Website: www.michigan.gov/energy ▸ Michigan Energy Office: www.michigan.gov/mdcd/0,4611,7-122-25676---,00.html ▸ Public Service Commission: www.michigan.gov/mpsc/0,1607,7-159-16393---,00.html ▸ RPS Implementation Report: www.michigan.gov/documents/mpsc/implementation_of_PA295_renewable_energy_411615_7.pdf

Renewable Energy in Minnesota

Summary

Minnesota has been diligent in providing financial incentives that help support its ranking as a top five ethanol-producing state and a leading producer of biomass and wind power. Minnesota also strengthened its renewable portfolio standard (RPS) this year by adopting a solar energy carve-out, which requires investor-owned utilities to supply at least 1.5% of their energy sales from solar power by 2020. This carve-out, coupled with new financial incentives for solar energy, is expected to increase the state's installed solar capacity to 450 MW. With continued policy support, the state's wind, solar, and bioenergy markets hold potential for further growth.

Installed Renewable Energy Capacity, 2012			
Wind Power	2,987 MW	Marine Power	0 MW
Solar Photovoltaic	11.3 MW	Biomass & Waste	491 MW
Solar Thermal Electric	0 MW	Ethanol	1,147.1 mGy
Geothermal Power	0 MW	Biodiesel	66 mGy
Hydropower	204 MW	**Totals**	3,693 MW; 1,213 mGy

Sources: See User's Guide for details

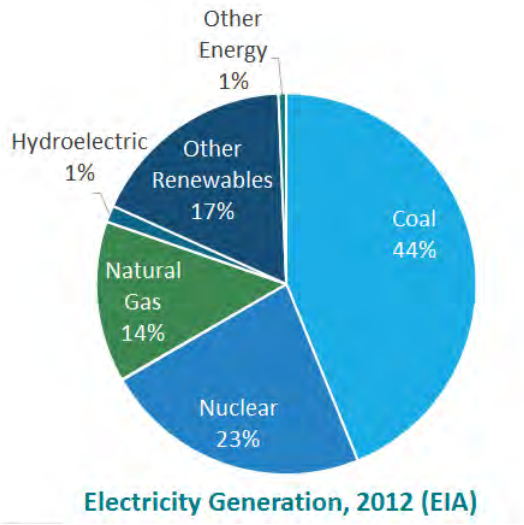
Market Spotlight

- A bio-based isobutanol facility came back online in June 2013 after being shut down the previous year, which can produce 18 million gallons per year. The isobutanol will be used as a building block to make jet fuel and chemical products.
- Developers in Minnesota added 267 MW of wind power capacity in 2012. The state currently ranks seventh in the nation for installed wind power capacity. The 200 MW Prairie Rose Wind Farm located in Rock and Pipestone Counties came online in 2012 and produces enough power to provide energy to up to 60,000 homes annually, enough to displace 360,000 tons of carbon dioxide.
- Minnesota's first community solar project celebrated its grand opening in September 2013, built by the Wright-Hennepin Cooperative Electric Association at its headquarters in Rockford. Co-op members have purchased individual solar panels and will receive credit on their utility bills for the electricity produced.
- At least nine waste-to-energy facilities produce electricity and steam from municipal solid waste, with a combined capacity of over 126 MW.

Economic Development

Employment	**2011**	
Green Goods & Services Jobs	75,302	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	$567.7m	$427.4m
Venture Capital & Private Equity	$14m	$16.7m

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

Renewable Energy in Minnesota

State Policy

Renewable Portfolio Standard	▸ 31.5% by 2020 for Xcel Energy; 26.6% by 2025 for other investor-owned utilities (IOUs); 25% by 2025 for other utilities ▸ For IOUs, 1.5% of total retail sales from solar PV; statewide goal of 10% solar by 2030 o 10% of the IOU solar PV requirement must come from systems ≤20 kW (incentivized by a $5m/year fund for the next five years)
Net Metering	▸ All utilities ▸ System capacity limit – *current rules*: 40 kW; *new rules*: 1 MW ▸ Net excess generation – *current rules and new rules for systems under 40 kW*: customer may receive payment or credit on next bill at the retail rate; *new rules*: customers with systems 40 kW-1 MW may receive credit at the avoided-cost rate or a kWh credit; excess credit reimbursed at end of calendar year at the avoided-cost rate
Interconnection Standards	▸ All utilities; system capacity limit of 10 MW ▸ Insurance requirements vary; external disconnect switch required
Rebates	**Made in Minnesota Solar Thermal Rebate:** ▸ 25% of installed costs for systems with components manufactured in Minnesota ▸ Maximum rebates – *single-family residential*: $2,500; *multi-family residential*: $5,000; *commercial*: $25,000; program budget of $250,000/year
Tax Incentives	**Sales Tax Exemption:** Applies to solar energy and wind power systems, and the materials used to manufacture, install, construct, repair or replace wind energy systems **Property Tax Exemption:** For real property taxes for solar PV and real and personal property taxes for wind; in lieu of property tax, wind projects charged a production tax **Investment Tax Credit:** For investments in small businesses that use or are involved in the research or development of cellulosic ethanol; 25% of investment, <$250,000 annually
Production Incentives	**Made in Minnesota Solar Energy Production Incentive:** Solar systems connected to the grid, less than 40 kW and made in state; 10-year contract; recalculated rates each year **Renewable Energy Production Incentive:** 1.5%/kWh for on-farm biogas facilities **Value of Solar Tariff:** Public utilities must offer this tariff or net metering
Loans	**Agricultural Improvement Loan Program:** ▸ Improvements or additions to permanent agricultural facilities, including wind energy (maximum 1 MW), anaerobic digestion, and certain other biomass systems ▸ Loans made by financial institutions; Minnesota Rural Finance Authority (RFA) participation limited to the lesser of 45% of loan principal or $300,000; 10 year max **Methane Digester Loan Program:** RFA participation limited to 45% of loan principal or $250,000; maximum term of 10 years; RFA portion at zero interest **Sustainable Infrastructure Revolving Loan Program:** ▸ On-farm energy production, including solar power, wind, and biomass, that results in improvement of the environment and of the farm's economic viability ▸ Up to $40,000 per farm family or up to $160,000 for joint projects; total budget $1m ▸ Fixed interest rate for up to 7 years (3% currently); 2:1 ratio of collateral to loan amount **Fix-up Loan:** Home improvement loans for renewable energy and energy efficient technologies; $2,000-$50,000; loan repayment 10-20 years
Biofuel Mandates	▸ Gasoline sold or offered for sale must contain 10% ethanol (will raise to 20% in 2015) ▸ Diesel sold or offered for sale must contain at least 5% biodiesel (should raise to 10% by 2014 and 20% in 2015)
Other Policies	▸ Each public utility must file with the Public Utility Commission to create a 20-year power purchase agreement (PPA) for community-owned renewable energy projects
More Info	▸ DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=MN ▸ Minnesota Department of Commerce (Energy): www.mn.gov/commerce/energy ▸ Minnesota Department of Agriculture (Energy): www.mda.state.mn.us/renewable.aspx

Renewable Energy in Missouri

Summary

Although Missouri's renewable energy industry is less developed than some of its neighboring states, it possesses an equally strong renewable energy resource potential, particularly well-suited for wind and bioenergy production. The state has enacted policies and tax incentives to help support the renewable energy industry's advancement, especially through the provisions in its renewable energy portfolio standard and its biofuels incentives. However, it did not see significant renewable energy investment activity or utility-scale capacity additions in the 2011-2012 time period, and still relies on coal generation to provide most of its power. In March 2013, the Missouri House voted to allow additional hydroelectric power to be used toward meeting the state's renewable energy requirement.

Installed Renewable Energy Capacity, 2012			
Wind Power	459 MW	Marine Power	0 MW
Solar Photovoltaic	18.5 MW	Biomass & Waste	9.8 MW
Solar Thermal Electric	0 MW	Ethanol	271 mGy
Geothermal Power	0 MW	Biodiesel	186 mGy
Hydropower	499.2 MW	**Totals**	987 MW; 457 mGy

Sources: See User's Guide for details

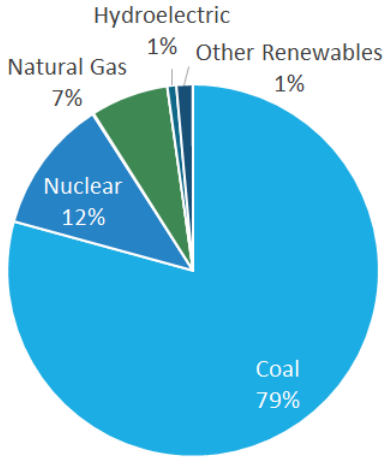
Market Spotlight

- The state ranks third in biodiesel production capacity nationwide. A developer is constructing a biodiesel plant near St. Louis to produce renewable jet fuel, which is expected to begin operations in 2013.
- The University of Missouri replaced a coal-fired boiler with a new biomass-fired boiler in July 2013. The new biomass boiler is fueled by more than 100,000 tons of woody biomass annually and will reduce fossil fuel usage on campus by 25%.
- Developers in Missouri installed more than 16 MW of small-scale solar energy installations in 2012. Kansas City recently signed agreements to install solar PV at 80 municipal buildings to reduce energy costs. Each system could be up to 25 kW in size.
- After adding a majority of its wind power capacity in the 2009 to 2010 period, Missouri did not install any large wind power projects in 2012.

Economic Development

Employment	**2011**	
Green Goods & Services Jobs	68,534	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	-	-
Venture Capital & Private Equity	-	-

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

Renewable Energy in Missouri

State Policy

Renewable Portfolio Standard	▸ 15% by 2021 ▸ Investor-owned utilities (IOUs) (representing 70% of the state's electric load) ▸ Solar power must meet 2% of annual requirement, to reach 0.3% of retail sales by 2021 ▸ In-state renewable energy is worth 25% more for compliance purposes ▸ Solar renewable energy credits (SRECs) can be used to comply with the solar target or the overall target ▸ IOUs must offer rebates of at least $2/watt for customer-sited solar power systems <25 kW, and may offer standard contracts for the purchase of SRECs ▸ Penalties imposed of twice the market value of RECs or SRECs for noncompliance
Net Metering	▸ All utilities ▸ System capacity limit of 100 MW; aggregate capacity limit of 5% of utility's single-hour peak load during previous year ▸ Net excess generation credited to next bill at avoided-cost rate for 12 months
Interconnection Standards	▸ All utilities ▸ Net metering required, other rules vary by utility, system type and/or system size
Tax Incentives	**Missouri Works Program:** Tax credits or retention of withholding tax for new and existing businesses creating or retaining jobs in state **Solar Property Tax:** Solar energy systems not held for resale are exempt from state, local, and county property taxes
Loans	**Energy Revolving Loan Program:** ▸ Applies to energy improvements made at schools, public water, and wastewater treatment facilities, public/private not-for-profit hospitals, and local governments, including the installation of renewable energy systems ▸ $5,000-$500,000 per applicant; $5m total available in FY2014
Fuel Production Incentive	**Ethanol Production Incentive:** ▸ Grantee must own at least 51% of production facility and produce ethanol for commercial purposes from Missouri agricultural products or qualified biomass ▸ For over 60 months at rate of $0.20/gallon for first 12.5 million gallons and $0.05 for next 12.5 million gallons ▸ Maximum $3.125m per producer per fiscal year
Renewable Fuel Mandate	▸ All gasoline sold at retail stations must contain 10% ethanol
More Info	▸ DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=MO ▸ Missouri Division of Energy: www.ded.mo.gov/division-of-energy/funding-opportunity ▸ Public Service Commission (RPS): www.efis.psc.mo.gov/mpsc/Filing_Submission/DocketSheet/docket_sheet.asp?caseno=EX-2010-0169&pagename=case_filing_submission_rst.asp

Renewable Energy in Nebraska

Summary

Nebraska's landscape has diverse and plentiful renewable energy resources. With its array of state tax incentives and loans, it has become a leader in the biofuels industry, but its other its renewable energy sectors are less notable. Nebraska is the only state in the nation where electricity is completely supplied by public power utilities, which are generally hindered from using the same utility financial incentives and operating structures for renewable energy as investor-owned utilities. Coal is responsible for nearly three-quarters of in-state electricity generation, and growth in state's renewable power markets may remain limited without a renewable portfolio standard.

Installed Renewable Energy Capacity, 2012			
Wind Power	459 MW	Marine Power	0 MW
Solar Photovoltaic	0.4 MW	Biomass & Waste	10.9 MW
Solar Thermal Electric	0 MW	Ethanol	2,058 mGy
Geothermal Power	0 MW	Biodiesel	5 mGy
Hydropower	332.3 MW	**Totals**	803 MW; 2,063 mGy

Sources: See User's Guide for details

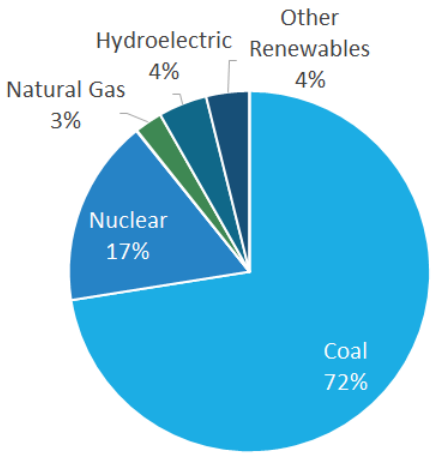
Market Spotlight

- Nebraska ranks second in the nation in ethanol production capacity. In May 2013, the U.S. Department of Defense chose South Sioux City to be the location of a biofuel plant that will power military jets and ships by 2016, as part of the Defense Production Act's Advanced Drop-In Biofuels Production Project.
- Although Nebraska ranks fourth in the nation for wind power potential, it only ranks 23rd in the nation for actual installed capacity (American Wind Energy Association).
- The 200 MW Prairie Breeze wind farm in Antelope, Boone, and Madison Counties is expected to begin commercial operations in 2014. The average annual output could power 60,000 homes.
- A proposed 220-mile-long transmission line in north-central Nebraska could open the door for the expansion of renewable energy in the state, while creating a means to sell excess energy to other utilities across state lines.

Economic Development

Employment	**2011**	
Green Goods & Services Jobs	22,392	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	$60.9m	$270.2m
Venture Capital & Private Equity	-	$2m

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

Renewable Energy in Nebraska

State Policy

Net Metering	▸ All utilities ▸ System capacity limit of 25 kW ▸ Aggregate capacity limit of 1% utility's average monthly peak demand ▸ Net excess generation credited to next bill at avoided-cost rate; carries over indefinitely ▸ Customer retains ownership of renewable energy credits (RECs)
Interconnection Standards	▸ All utilities ▸ Net metering required
Tax Incentives	**Sales and Use Tax Exemption for Community Wind Projects:** ▸ Community wind project owners can include Nebraskan residents, limited liability companies, nonprofit corporations, electric suppliers, and/or tribal councils ▸ At least 33% of power purchase agreement payments must be paid to the owners or local community **Sales and Use Tax Exemption for Renewable Energy Property:** ▸ Equipment investment must meet or exceed $20m ▸ For systems used to produce electricity for sale **Property Tax Exemption for Wind Energy Generation Facilities:** ▸ Nameplate capacity tax charged in lieu of property tax for wind power projects ▸ Both the property tax and nameplate capacity tax are exempt if project is owned by the government, certain electricity suppliers, electricity customers who install a turbine on their side of the meter, and certain other groups **Renewable Energy Tax Credit** *(Personal or Corporate)*: ▸ Program budget of $50,000 ▸ Electricity generated in 2013 or after receives a credit of 0.05 cents/kWh ▸ Credits available for a 10-year period **Cellulosic Ethanol Investment Tax Credit:** ▸ Credit for up to 40% of the amount invested in a cellulosic ethanol-related small businesses, up to $350,000 ▸ Up to $3m available annually through the program **Biodiesel Production Investment Tax Credit:** ▸ Credit for up to 30% of the amount invested in a biodiesel production facility that produces B100, up to $250,000 **Ethanol and Biodiesel Motor Fuel Tax Exemption:** ▸ Applies to motor fuels sold to an ethanol or biodiesel production facility and motor fuels manufactured at and sold from an ethanol or biodiesel facility
Loans	**Dollar and Energy Savings Loan:** ▸ Low-interest loans for residential and commercial energy efficiency improvements, including the installation of renewable energy systems ▸ Interest rate of 2.5%-5% ▸ Payback term of 5-15 years ▸ Largest loan offered is $750,000 for non-residential case-by-case basis loans
More Info	▸ DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=NE ▸ Nebraska Energy Office: www.neo.ne.gov ▸ Power Review Board: www.nprb.state.ne.us ▸ Department of Revenue: www.revenue.ne.gov/incentiv/incentive_index.html

Renewable Energy in North Dakota

Summary

As one of the top energy consumers per capita, wind energy, hydropower, and other renewable energy generation together constitute nearly a quarter of North Dakota's power portfolio. Coal is the only other notable source of electricity generation in the state, providing over three quarters of the state's power. North Dakota's renewable energy installations have increased significantly over the past five years, but much of its wind resource potential still remains untapped. An array of state tax incentives, loan programs, and other incentives encourage developers to take advantage of the state's outstanding renewable resources; however, historically low energy prices command conventional energy generation.

Installed Renewable Energy Capacity, 2012			
Wind Power	1,680 MW	Marine Power	0 MW
Solar Photovoltaic	0.1 MW	Biomass & Waste	9.8 MW
Solar Thermal Electric	0 MW	Ethanol	370 mGy
Geothermal Power	0 MW	Biodiesel	88 mGy
Hydropower	614 MW	**Totals**	2,304 MW; 458 mGy

Sources: See User's Guide for details

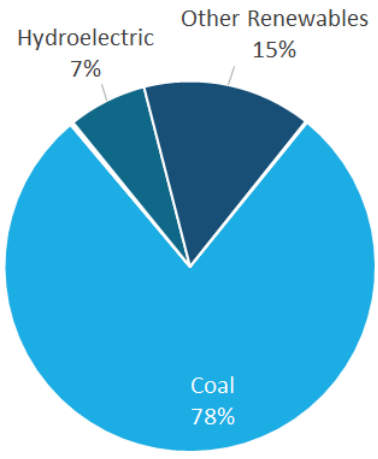
Market Spotlight

- North Dakota is the 10th largest ethanol producing state in the nation. Plants in Casselton and Hankinson produce more than 230 million gallons of corn ethanol per year.
- In 2012, North Dakota ranked 11th in the nation for installed wind power capacity. The 292 MW Bison Wind Energy Center in Oliver and Morton Counties marked completion in December 2012, which exports power to Minnesota over a 465-mile direct current transmission line.
- The Dakota Spirit AgEnergy ethanol plant broke ground in August 2013. The refinery will produce 65 million gallons of ethanol per year and will purchase 23 million bushels of corn annually from area farmers.
- A three-year research project is currently underway at North Dakota State University, intended to advance development for the state's first facility that will use beets to produce biofuels.

Economic Development

Employment	2011	
Green Goods & Services Jobs	9,481	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	-	$311.2m
Venture Capital & Private Equity	-	-

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

Renewable Energy in North Dakota

State Policy

Renewable and Recycled Energy Objective

- 10% by 2015 (voluntary)
- All utilities
- Eligible resources include most renewable energy systems and certain waste heat, and should be cost effective

Net Metering

- Investor-owned utilities (IOUs)
- System capacity limit of 100 kW
- Net excess generation reconciled monthly at avoided-cost rate

Tax Incentives

Renewable Energy Tax Credit *(Corporate)*:

- 3% per year for five years (15% total) of the actual cost to acquire and install a renewable energy system
- Excess credit from new systems may be carried over for 10 years

Geothermal Tax Credit *(Personal)***:**

- 3% per year for five years (15% total) for the cost of acquiring and installing a geothermal energy system on a property owned or leased by the taxpayer
- Excess credit may be carried over for 10 years

Sales and Use Tax Exemption for Electrical Generating Facilities:

- Facilities must have a capacity of at least 100 kW
- For the purchase of building materials, production equipment, and any other tangible personal property used for constructing or expanding an electrical generation facility

Biodiesel Blender Credit:

- $0.05/gallon for diesel fuel blended with at least 5% biodiesel or green diesel
- May be carried forward five years

Large Wind Property Tax Reduction: 70% or 85% reduction in property taxes on centrally-assessed wind turbines ≥100 kW

Renewable Energy Property Tax Exemption: For five years for locally-assessed solar, wind or geothermal energy devices serving buildings or structures

Sales and Use Tax Exemption for Gas Processing Facilities: For materials, equipment, and other tangible property used to build or expand a landfill gas facility

Sales Tax Exemption for Hydrogen Generation Facilities: For the sale of hydrogen used to power an internal combustion engine or fuel cell, or for equipment used to produce and store hydrogen

Agriculturally-Based Fuel Production Wage and Salary Tax: New biofuel producers may be eligible for an income tax credit equal to a percentage of wages and salaries paid

Loans

Biofuels Partnership in Assisting Community Expansion (PACE) Loan Program:

- Interest buy down of up to 5% below the note rate for biodiesel, ethanol or green diesel production facilities and certain support facilities
- Up to $500,000 for the purchase, construction, or expansion of a production facility or for the purchase or installation of equipment at the facility

Agriculturally-Derived Fuel Production Facility Loan Guarantees:

- For the construction of biofuel production facilities that use agricultural feedstocks
- May not exceed 30% of the total loan, up to $2.5m

Other Incentives

- Ethanol production incentive based on the wholesale ethanol price and the average state corn price for the preceding quarter; cumulative incentive of $1.6m
- Matching grants and other assistance to support research and development of advanced and sugar-based biofuels

More Info

- DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=ND
- Department of Commerce: www.communityservices.nd.gov/energy
- State Tax Incentives: www.nd.gov/tax/taxincentives
- Public Service Commission: www.psc.nd.gov

Renewable Energy in Ohio

Summary

Ohio is a key player in the Midwest wind supply chain due to its proximity to large wind energy markets, but the state's production of wind energy has not reached the scale of some of its neighbors. The state is one of the nation's top ten ethanol producers and has the largest amount of installed solar energy capacity in the Midwest. With significant renewable energy resources from wind power, solar power, and bioenergy, as well as a multifaceted renewable energy policy portfolio, the state has tremendous potential to expand its emerging renewable energy markets.

Installed Renewable Energy Capacity, 2012			
Wind Power	428 MW	Marine Power	0 MW
Solar Photovoltaic	79.9 MW	Biomass & Waste	185.8 MW
Solar Thermal Electric	0 MW	Ethanol	538 mGy
Geothermal Power	0 MW	Biodiesel	132 mGy
Hydropower	128.6 MW	**Totals**	822 MW; 670 mGy

Sources: See User's Guide for details

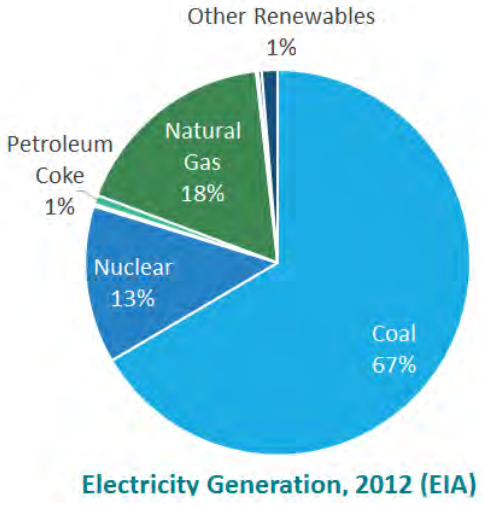
Market Spotlight

- Solar installations are on the rise in Ohio, with 25 MW of new capacity added in 2012. In April 2013, a 5 MW solar PV plant came online in Mercer County creating 108 construction jobs.
- A number of biogas plants throughout the state capture methane from landfills to produce energy. A new biogas facility at the Mahoning Landfill came online in 2013, which has a capacity of 4.8 MW.
- The U.S. Department of Agriculture awarded small rural and agricultural businesses in Ohio more than $1.1 million in grants in August 2013 to help reduce the use of conventional energy and increase the use of renewable energy.
- Ohio State University researchers are evaluating the use of flax and camelina for biofuel, to help diversify Ohio farms and boost their sustainability.

Economic Development

Employment	**2011**	
Green Goods & Services Jobs	137,143	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	$194.6m	$71.4m
Venture Capital & Private Equity	$6.1m	$14.9m

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

Renewable Energy in Ohio

State Policy

Alternative Energy Portfolio Standard	▸ 12.5% by 2024 (renewable energy), 12.5% by 2025 (advanced energy) ▸ Investor-owned utilities (IOUs) and retail electric suppliers (representing 88.6% of state's electric load) ▸ Solar energy must account for 0.5% of the total electricity supply by 2024 (part of overall renewable energy requirement) ▸ Renewable energy requirement includes certain cogeneration and waste heat recovery system technologies as well as distributed generation ▸ Penalties imposed if standard not met ▸ Renewable energy credits (RECs) and solar RECs may be used to meet the standard
Net Metering	▸ IOUs ▸ Net excess generation credited to customer's next bill at unbundled generation rate; customer may be paid for excess credit at end of 12 months
Interconnection Standards	▸ IOUs ▸ System capacity limit of 20 MW
Tax Incentives	**Energy Conversion and Thermal Efficiency Sales and Use Tax Exemption:** ▸ For certain tangible personal property used in energy conversion, solid waste energy conversion, or thermal efficiency improvement facilities **Qualified Energy Property Tax Exemption:** ▸ Qualified energy projects over 250 kW are subject to a payment in lieu of personal property taxes and real property taxes ▸ Qualified energy projects 250 kW or less are exempt from public utility tangible personal property taxes and real property taxes and are not subject to an extra payment in lieu of the taxes **Air Improvement Tax Incentives:** ▸ May include a full tangible personal property tax exemption; real property tax exemption; corporate franchise tax reduction; and/or sales and use exemption ▸ Qualifying projects include renewable energy production, including biofuel **Ethanol Production Investment Tax Credit:** ▸ Equal to 50% of an investment in a certified ethanol production plant against the state corporation franchise tax and income taxes, up to $5,000 per taxpayer per plant
Loans	**Energy Loan Fund:** ▸ Small businesses, manufacturers, nonprofits, and public entities ▸ Interest rate equal to or less than market rate; $250 application fee; 1% processing and commitment fee; 0.25% annual servicing fee ▸ Projects must reduce energy consumption by 15% and result in a return on investment in 15 years or less **Energy Conservation for Ohioans:** ▸ Reduced rate financing for energy efficiency and renewable energy home upgrades ▸ 3% loan rate reduction through participating banks ▸ Maximum loan rate reduction of $50,000 and for seven years of bank loan
More Info	▸ DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=OH ▸ Public Utilities Commission (RPS): www.puco.ohio.gov/puco/index.cfm/industry-information/industry-topics/ohioe28099s-renewable-and-advanced-energy-portfolio-standard ▸ Development Services Agency (Energy): www.development.ohio.gov/bs/bs_renewenergy.htm ▸ Air Quality Development Authority (Energy): www.ohioairquality.org/energy

Renewable Energy in South Dakota

Summary

Hydropower and wind power account for nearly three-quarters of South Dakota's electricity generation, and the state has a significant opportunity to further develop its renewable energy resources and export sustainable energy to other states. The state is also a leading producer of ethanol. Nevertheless, it has not seen significant renewable energy investment activity or utility-scale capacity additions since the beginning of 2011. And unlike most other states, it does not have net metering standards to encourage the deployment of distributed generation systems, like solar energy.

Installed Renewable Energy Capacity, 2012			
Wind Power	783 MW	Marine Power	0 MW
Solar Photovoltaic	0 MW	Biomass & Waste	0 MW
Solar Thermal Electric	0 MW	Ethanol	1,016 mGy
Geothermal Power	0 MW	Biodiesel	7 mGy
Hydropower	1,598.1 MW	**Totals**	2,381 MW; 1,023 mGy

Sources: See User's Guide for details

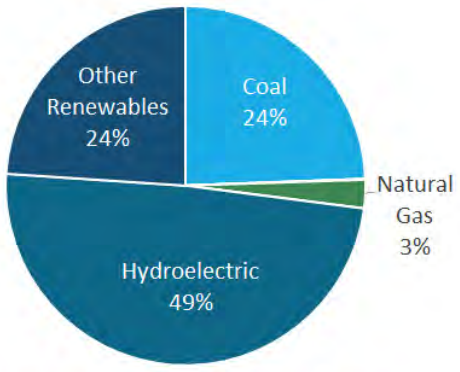
Market Spotlight

- A cellulosic ethanol pilot plant in the city of Scotland uses cobs from previous corn harvests and corn fiber extracted from an adjacent corn ethanol production facility to produce fuel.
- South Dakota provided 23.9% of its electricity from wind power in 2012, the second highest percentage of any state (American Wind Energy Association). However, its installed wind power capacity only ranks 16th nationally.
- The first ever Native American intertribal wind project was announced in August 2013, which plans to unite six South Dakota Tribes to create revenue and energy for the state.
- At least four recovered energy plants operate in the state that produce energy by using waste heat from natural gas turbines.

Economic Development

Employment	**2011**	
Green Goods & Services Jobs	10,578	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	-	-
Venture Capital & Private Equity	-	-

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

Renewable Energy in South Dakota

State Policy

Renewable, Recycled and Conserved Energy Objective	▸ 10% by 2015 (voluntary) ▸ All utilities (no penalty for non-compliance) ▸ Eligible systems include most renewable energy generation as well as certain waste heat and hydrogen production ▸ Annual reporting required through 2017
Interconnection Standards	▸ Investor-owned utilities (IOUs) ▸ System capacity limit of 10 MW ▸ Insurance requirements vary by system size and/or type
Tax Incentives	**Wind Energy Facility Sales and Use Tax Reimbursement:** ▸ Up to 100% of tax paid on project costs for new or expanded wind power facilities (that cost more than $20m) or equipment upgrades (that cost more than $2m) **Renewable Energy System Property Tax Incentives:** ▸ For the greater of $50,000 or 70% of the assessed value of eligible property **Large Commercial Wind Exemption and Alternative Taxes:** ▸ Alternative taxation in lieu of real and personal property taxes imposed by the state, county, municipality, school district, and other political subdivisions ▸ Calculated as $3/kW of system capacity and 2% of the gross receipts of the wind farm **Biodiesel Blend Tax Credit:** ▸ Granted on a per gallon basis in the amount that the rate for diesel fuel exceeds the rate for the biodiesel blend
Fuel Production Incentive	**Ethanol and Biobutanol Production Incentive:** ▸ $0.20/gallon for ethanol and biobutanol fully distilled and produced in state ▸ Ethanol must be denatured, 99% pure, distilled from cereal grains, and blended with gasoline ▸ Annual incentives may not exceed $1m per facility, or $4.5m for the overall program in 2014
More Info	▸ DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=SD ▸ Statewide Energy Management: www.state.sd.us/boa/ose/OSE_Statewide_Energy.htm ▸ Public Utilities Commission: www.puc.sd.gov

Renewable Energy in Wisconsin

Summary

With its vast natural resources, Wisconsin has the opportunity to develop its renewable energy market to meet or exceed its 10% renewable portfolio standard (RPS). Wisconsin's high corn production makes it one of the nation's leading producers of ethanol. It also provides an attractive location for solar and wind manufacturing facilities due to its proximity to clean energy supply chains and favorable incentives for manufacturers. In order to support the continued scale-up of clean technologies, the state has enacted an array of financial incentives, particularly for biomass, solar, and wind energy.

Installed Renewable Energy Capacity, 2012			
Wind Power	648 MW	Marine Power	0 MW
Solar Photovoltaic	21.1 MW	Biomass & Waste	358.1 MW
Solar Thermal Electric	0 MW	Ethanol	504 mGy
Geothermal Power	0 MW	Biodiesel	32.6 mGy
Hydropower	657.1 MW	**Totals**	1,684 MW; 537 mGy

Sources: See User's Guide for details

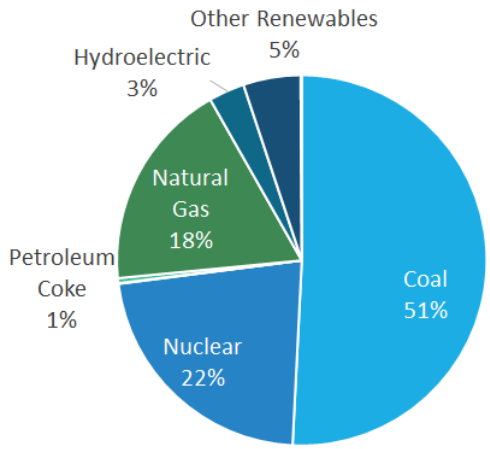
Market Spotlight

- A next-generation biodiesel facility located in Park Falls became operational in May 2012. Processing 1,000 dry tons of forest waste per day, the plant will have an installed capacity of 18 million gallons of biodiesel per year.
- Wisconsin is a leader in anaerobic digestion, and biomass facilities in the state also produce electricity through landfill gas power, gasification, anaerobic digestion, and combustion. At least two waste-to-energy facilities produce electricity and steam from municipal solid waste, with a combined capacity of over 28 MW.
- Testing began in July 2013 on a 50 MW biomass power plant that will burn approximately 500,000 tons of biomass supplied by local sawmills, paper mills, and loggers. The plant is expected to be fully operational before the end of 2013, while generating enough power to supply 32,000 homes.
- Solar energy capacity doubled in 2012, mostly from residential and commercial solar capacity additions.

Economic Development

Employment	**2011**	
Green Goods & Services Jobs	69,647	
Investment (Grossed-up)	**2011**	**2012**
Asset Finance	$254.3m	-
Venture Capital & Private Equity	$1.2m	-

Sources: Bureau of Labor Statistics (BLS); Bloomberg New Energy Finance (BNEF). See User's Guide for details.



Electricity Generation, 2012 (EIA)

Renewable Energy in Wisconsin

State Policy

Renewable Portfolio Standard	▸ 10% by 2015 (statewide, varies by utility) ▸ All electricity providers ▸ Renewable energy certificates (RECs) and renewable resource credits (RRCs) may be used for compliance
Net Metering	▸ Investor-owned utilities (IOUs), municipal utilities ▸ System capacity limit of 20 kW; for some utilities 100 kW ▸ Net excess generation varies by utility, generally credited to next bill at retail rate
Interconnection Standards	▸ IOUs, municipal utilities ▸ System capacity limit of 15 MW ▸ External disconnect switch generally required; insurance requirements vary by system size and/or type
Public Benefit Fund	**Focus on Energy:** ▸ Funded by state's IOUs and by participating municipal and electric co-ops ▸ Utilities required to spend 1.2% of annual operating revenue on efficiency and renewables; fund for 2014 is $10m for renewables ▸ Provides financial assistance, information, technical assistance and other services
Rebates and Grants	**Residential Renewable Energy Rebates:** ▸ Rebates for geothermal heat pumps; incentives for solar thermal and PV suspended ▸ Funding available (as of September 2013): $40,881; maximum rebate $650 per system **Renewable Energy Competitive Incentive Program (RECIP):** ▸ Competitive request for proposals process for businesses that install qualifying renewable energy systems ▸ Rates may not exceed $0.50/kWh or $1.00/Therm produced or offset ▸ Incentives range from $5,000-$500,000
Tax Incentives	**Sales Tax Exemption:** ▸ Eligible purchases for solar, landfill gas, wind, biomass, and anaerobic digestion energy systems are exempt from sales and use taxes **Property Tax Exemption:** ▸ The value added by a solar or wind energy system is exempt from property taxes **Woody Biomass Harvesting and Processing Tax Credit** *(Personal or Corporate)***:** ▸ 10% of the cost of equipment used to harvest or produce woody biomass for use as a fuel or as a component of fuel ▸ Maximum credit is $100,000; total credits may not exceed $900,000 per year ▸ Excess credit in a given year is refunded to taxpayer
More Info	▸ DSIRE Database: www.dsireusa.org/incentives/index.cfm?state=WI ▸ Focus on Energy: www.focusonenergy.com ▸ Public Service Commission (RPS): www.psc.wi.gov/utilityInfo/electric/renewableResource.htm ▸ State Energy Office: www.energyindependence.wi.gov

User's Guide

Overview

This report is intended to provide an executive summary on the status of renewable energy implementation at the state-level. To accomplish this objective, the report provides a two-page, high-level overview on the key developments that have shaped the renewable energy landscape in each state, including information on installed and planned capacity, market trends, economic development, resource potential, and policy.

The report does not attempt to evaluate or rank success in state utilization of renewable energy. There is no one silver bullet for success in the industry; rather, it is a combination of policies and investment in addition to resources that lead to well-established markets. All factors are not explored in this report, but there is emphasis on strong market drivers such as policies, investment trends, proximity to supply chains, resource potentials, and related factors that cause investors and companies to develop renewable energy projects, manufacturing plants, and research centers within a state's borders.

Although states have taken great strides in the advancement of many clean technologies, the technologies profiled in this report are renewable energy technologies exclusively. The report assumes some familiarity with the renewable energy industry, and technical terms are defined in glossary.

Each state summary is divided into the following sections:

- Summary
- Capacity Chart
- Market Spotlight
- Economic Development
- Electricity Generation by Source
- Policies

Capacity Chart

The capacity chart reflects the nameplate capacity of renewable energy projects that were in operation before the end of the last full year. The capacity is represented in megawatts (MW) for electricity and million gallons per year (mGy) for fuels. The information in this section is provided by public sources, and ACORE does not independently verify the data or guarantee its accuracy. The sources used are well-cited within the industry and include: the American Wind Energy Association (AWEA), the Interstate Renewable Energy Council (IREC), the Renewable Fuels Association (RFA), the Geothermal Energy Association (GEA), Biodiesel Magazine, Bloomberg New Energy Finance (BNEF), and the U.S. Energy Information Agency (EIA). The sources for each section include:

- Wind data reflects utility-scale wind power installations and is from AWEA's *U.S. Wind Industry Fourth Quarter 2012 Market Report*.
- Solar photovoltaic (PV) data is from IREC's *U.S. Solar Market Trends 2012* report. The report's data was obtained from state agencies; organizations administering state incentive programs; utility companies that manage incentive programs and/or interconnection agreements; and nonprofit organizations (through surveys).
- Geothermal power data is from GEA's *2013 Annual US Geothermal Power Production and Development Update*, released in April 2012. Information is provided by developers or public sources, and is not independently verified by GEA.
- Ocean power data and concentrating solar power data are derived from the BNEF project database. Ocean power data includes tidal, wave, and ocean thermal energy conversion (OTEC) technologies.
- Hydropower data and biomass power data are derived from the Energy Information Agency's Form EIA-860. Biomass power data includes capacity from biomass facilities that use combustion, anaerobic digestion, gasification, co-firing, landfill gas or pyrolysis to produce electricity.

- Bioethanol data is from RFA's *2013 Ethanol Industry Outlook* and represents nameplate capacity in million gallons per year (mGy).
- Biodiesel data is from the Biodiesel Magazine USA plants list and represents nameplate capacity in million gallons per year (mGy).

Market Spotlight

This section of the report includes highlighted characteristics and developments of the state's renewable energy industry, including information on existing and proposed projects, manufacturing, research and development, and other market trends. The information was collected from state Energy Department and Public Utility Commission websites, other state-funded resources, the Bloomberg New Energy Finance (BNEF) desktop, and news articles.

Economic Development

This section provides information about the economic impact renewable energy has had in each state. It should be noted that some of the totals in this section also reflect investment in other "green" sectors, like energy efficiency, in addition to renewable energy.

Bloomberg New Energy Finance (BNEF), a world leader in industry information and analysis, provided information on renewable energy venture capital, private equity and asset finance transactions. The report's Economic Development section indicates the grossed-up estimates for completed, BNEF-tracked deals over the past two years. Venture capital and private equity transactions reflect new investment in renewable energy technology and early stage companies. Asset finance transactions reflect the funds committed for newly-built renewable energy projects, including debt and equity finance and funding from internal company balance sheets.

Jobs data provided for the report, by the Bureau of Labor Statistics (BLS), estimates all jobs (public and private) created by the "green goods and services" (GGS) industry. BLS defines GGS jobs as: "Jobs in businesses that produce goods or provide services that benefit the environment or conserve natural resources. These goods and services are sold to customers, and include research and development, installation, and maintenance services." Jobs in this industry fall into one or more of the following five categories: energy from renewable sources; energy efficiency; pollution reduction and removal, greenhouse gas reduction, and recycling and reuse; natural resources conservation; and/or environmental compliance, education and training, and public awareness. For more information, visit: http://www.bls.gov/ggs/ggsfaq.htm.

Electricity Generation

These pie charts indicate the percentage of power generation from each energy source in 2012. The data is from EIA's *Monthly Energy Review: February 2013*, using the generation totals from January to December 2012.

Policies

The policies profiled in this report reflect major state-level rules, regulations, financial incentives, and other policies for renewable energy that were enacted and operating as of the date of the most recent update. A main source for this information is the Database of State Incentives for Renewables & Efficiency (DSIRE), a comprehensive source of information on state, local, utility and federal incentives, and policies that promote renewable energy and energy efficiency. ACORE also utilized the U.S. Department of Energy's Alternative Fuels Data Center for information on biofuels incentives and laws.

Not all of the renewable energy policies in each state are included. Preference is given to policies implemented at the state-level with the most significant impact. The policies highlighted include: renewable portfolio standards (RPS) and goals, net metering programs, interconnection standards, rebates, tax incentives, production incentives, public benefit funds, grants, loans, renewable fuel mandates/standards, and other major

state-level policies. These terms are defined in the glossary.

The highlighted policies are for informational purposes only and should not be used as legal guidance in any way. The reader should refer to state government websites, the DSIRE database, or the Alternative Fuels Data Center for more information.

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Renewable Energy in the 50 States was crafted to illustrate a snapshot of renewable energy of each state, highlighting the state's progress in utilizing its available resources to increase renewable energy's share in its existing energy mix. This report does not attempt to be fully comprehensive, forecast success or failure, or compare one state against another. Instead, it is intended to educate the reader about what each state is actively doing to tap into its renewable energy resources.

Renewable Energy in America is a "living" document that will continue to evolve with updates and periodic revision. The renewable energy landscape is changing continually at the state-level, and ACORE will strive to maintain the accuracy of the report by updating annually.

Please note that this report contains a collection of research and data from well-cited, reliable sources, which was not independently verified by ACORE. The report should not be used to make decisions on project development or for legal advice.

Glossary

Ad Valorem Taxation: A tax based on the assessed value of real estate or personal property. Property ad valorem taxes are the major source of revenues for state and municipal governments.

Alternative Compliance Payment (ACP): In lieu of standard means of compliance with renewable portfolio standards, electricity suppliers may make alternative compliance payments to make up for deficiencies (in megawatt-hours) between the amount of electricity from renewable resources mandated and the amount actually supplied. Payment amount varies among states.

American Recovery and Reinvestment Act (Recovery Act): The Recovery Act was signed into law by President Obama on February 17, 2009. A direct response to the economic crisis, the Recovery Act has three immediate goals: create new jobs and save existing ones; spur economic activity and invest in long-term growth; and foster unprecedented levels of accountability and transparency in government spending. The Recovery Act has since allocated $1.64 billion (as of August 2010) to develop clean renewable resources in order to double America's supply of renewable energy and boost domestic renewable manufacturing capacity.

Anaerobic Digestion: The complex process by which organic matter is decomposed by anaerobic bacteria. An anaerobic digester optimizes the anaerobic digestion of biomass and/or animal manure, and possibly recovers biogas for energy production.

Avoided Cost: An investment guideline describing the value of a conservation or generation resource investment by the cost of more expensive resources that a utility would otherwise have to acquire.

Bagasse: The fibrous material remaining after the extraction of juice from sugarcane. It is often burned by sugar mills as a source of energy.

Bi-Directional Meter: A single meter used in net metering that allows for the monitoring of energy consumption by a residential system and the amount of excess energy exported back into the grid.

Biodiesel: A biodegradable transportation fuel for use in diesel engines that is produced according to strict quality specifications. Biodiesel is produced through the transesterification of organically-derived vegetable or animal oils or fats. It may be used either as a replacement for or as a component of diesel fuel.

Bioenergy: Useful, renewable energy produced from organic matter, which may either be used directly as a fuel or processed into liquids and gases.

Bioethanol: Ethanol produced from biomass feedstocks. This includes ethanol produced from the fermentation of crops, such as corn, as well as cellulosic ethanol produced from woody plants or grasses.

Biofuels: Liquid fuels and blending components produced from biomass (plant) feedstocks, used primarily for transportation. Biofuels include ethanol, biodiesel, and methanol.

Biogas: A combustible gas derived from decomposing biological waste under anaerobic conditions. Biogas normally consists of 50 to 60 percent methane. See also landfill gas.

British Thermal Unit (Btu): A measure of the heat content of fuels. It is the quantity of heat required to raise the temperature of 1 pound of liquid water by 1°F at the temperature that water has its greatest density (approximately 39°F). 1 kilowatt hour of electricity equals 3,412 Btu.

BXX (i.e. B20): A blend of petroleum diesel with a percentage of biodiesel. For example, B20 contains 20% biodiesel and 80% petroleum diesel. B100 is pure biodiesel and contains no petroleum diesel.

Camelina Feedstock: A rapid growth, omega-3 rich oilseed and non-food feedstock.

Capacity: The load that a power generation unit or other electrical apparatus or heating unit is rated by the manufacture to be able to meet or supply. Installed generator nameplate capacity is commonly expressed in megawatts (MW) and is usually indicated on a nameplate physically attached to the generator (referred to as "nameplate capacity").

Cellulosic Ethanol: While conventional ethanol is derived from soft starches (corn for example), cellulosic ethanol is derived from a wide variety of sources of cellulose (cell wall) plant fiber. These range from stalks and grain straw to switchgrass and quick-growing trees (poplar and willow)—and even municipal waste.

Combined Cycle: An electric generating technology in which electricity is produced from otherwise lost waste heat exiting from one or more gas (combustion) turbines. The exiting heat is routed to a conventional boiler or to a heat recovery steam generator for utilization by a steam turbine in the production of electricity. Such designs increase the efficiency of the electric generating unit.

Combined Heat & Power (CHP): Also known as cogeneration, CHP is the simultaneous production of electricity and heat from a single fuel source such as natural gas, biomass, biogas, coal, waste heat or oil.

Concentrated Solar Thermal (CSP): A solar energy conversion system characterized by the optical concentration of solar rays through an arrangement of mirrors to generate a high temperature working fluid which generates steam to drive a turbine to produce electricity .

Conservation Reserve Program (CRP): The Conservation Reserve Program (CRP) provides technical and financial assistance to eligible farmers and ranchers to address soil, water, and related natural resource concerns on their lands in an environmentally beneficial and cost-effective manner. The program provides assistance to farmers and ranchers in complying with Federal, State, and tribal environmental laws, and encourages environmental enhancement. The program is funded through the Commodity Credit Corporation (CCC). CRP is administered by the Farm Service Agency, with NRCS providing technical land eligibility determinations, conservation planning and practice implementation.

Consumer-Owned Utility: A municipal electric utility, a people's utility district or an electric cooperative.

Cord: The measure of an amount of wood that is 4 x 4 x 8 feet, or 128 cubic feet.

Crop Residue: Agricultural crop residues are the plant parts, primarily stalks and leaves, not removed from the fields with the primary food or fiber product. Examples include corn stover (including stalks, leaves, husks, and cobs), wheat straw, and rice straw.

Distributed Generation (DG): Small, modular, decentralized, grid–connected or off–grid energy systems located in or near the place where energy is used.

Electric Cooperative: A member-owned electric utility company serving retail electricity customers. Electric cooperatives may be engaged in the generation, wholesale purchasing, transmission, and/or distribution of electric power to serve the demands of their members on a not-for-profit basis.

EXX (i.e. E15): A blend of gasoline with a percentage of ethanol. For example, E15 contains 15% ethanol and 85% gasoline. E100 is pure ethanol without any added gasoline. The U.S. Environmental Protection Agency has approved E15 for use in model year 2001 and newer cars, light-duty trucks, medium duty passenger vehicles (SUVs), and all flex-fuel vehicles (FFVs).

Feasibility Project: Analysis and evaluation of a proposed project to determine if it (1) is technically feasible, (2) is feasible within the estimated cost, and (3) will be profitable. Feasibility studies are almost always conducted where large sums are at stake.

Federal Energy Regulatory Commission (FERC): An independent federal agency that regulates the interstate transmission of electricity, natural gas, and oil. FERC also reviews proposals to build liquefied natural gas (LNG) terminals and interstate natural gas pipelines as well as licensing hydropower projects. The Energy Policy Act of 2005 gave FERC additional responsibilities as outlined in FERC's Top Initiatives and updated Strategic Plan.

Feed-in Tariff: A policy that requires utilities to pay a fixed, premium rate for renewable energy generation

Ad Valorem Taxation: A tax based on the assessed value of real estate or personal property. Property ad valorem taxes are the major source of revenues for state and municipal governments.

Feedstock: Any material used as a fuel directly or converted to another form of fuel or energy product.

Flat Plate Collector: A solar thermal collection device in which heat collection takes place through a thin absorber sheet backed by an array of tubing that is placed within an insulated casing.

Forest Residue: Logging residues and other removable material left after carrying out silviculture operations and site conversions. Forest slash or logging residues are the portions of the trees that remain on the forest floor or on the landing after logging operations have taken place.

Fuel Cells: One or more cells capable of generating an electrical current by converting the chemical energy of a fuel directly into electrical energy. Fuel cells differ from conventional electrical cells in that the active materials such as fuel and oxygen are not contained within the cell but are supplied from outside.

Gasification and Catalytic Processes: A method for converting coal, petroleum, biomass, wastes, or other carbon-containing materials into a gas that can be burned to generate power or processed into chemicals and fuels. A refining process using controlled heat and pressure with catalysts to rearrange certain hydrocarbon molecules, there by converting paraffinic and naphthenic type hydrocarbons (e.g., low octane gasoline boiling range fractions) into petrochemical feedstocks and higher octane stocks suitable for blending into finished gasoline.

Geothermal Heat Pumps (GHP): A heat pump in which the refrigerant exchanges heat (in a heat exchanger) with a fluid circulating through an earth connection medium (ground or ground water). The fluid is contained in a variety of loop (pipe) configurations depending on the temperature of the ground and the ground area available. Loops may be installed horizontally or vertically in the ground or submersed in a body of water.

GW(h): One billion watt-hours (gigawatt-hour).

Independent Power Producer (IPP): A corporation, person, agency, authority, or other legal entity or instrumentality that owns or operates facilities for the generation of electricity for use primarily by the public, and that is not an electric utility.

Interconnected: Two or more electric systems having a common transmission line that permits a flow of energy between them. The physical connection of the electric power transmission facilities allows for the sale or exchange of energy.

Interconnection Standards: The technical and procedural process by which a customer connects an electricity-generating system to the grid. Interconnection standards include the technical and contractual arrangements that system owners and utilities must abide by. Standards for systems connected at the distribution level are typically adopted by state public utility commissions, while the Federal Energy Regulatory Commission (FERC) has adopted standards for systems connected at the transmission level. Most states have adopted interconnection standards, but some states' standards apply only to investor-owned utilities - not to municipal utilities or electric cooperatives.

Investment Tax Credit (ITC): The ITC is a federal tax credit based on a percentage of a taxpayer's investment in qualifying energy property. For example, if the taxpayer's investment in qualifying energy property is $100 and the credit rate is 30%, the amount of the ITC is $30. In general, the investment in energy property is the cost of the facility.

Investor-Owned Utility (IOU): A privately-owned electric utility whose stock is publicly traded. An IOU is rate regulated and authorized to achieve an allowed rate of return.

Kinetic Energy Capture: Energy available as a result of motion that varies directly in proportion to an object's mass and the square of its velocity.

kW(h): One thousand watt-hours (kilowatt-hour).

Landfill Gas: Gas that is generated by decomposition of organic material at landfill disposal sites.

mGy: Million gallons per year.

Municipal Solid Waste – Any organic matter, including sewage, industrial and commercial wastes, from municipal waste collection systems. Municipal waste does not include agricultural and wood wastes or residues.

Municipal Utility: A provider of utility services owned and operated by a city government.

MW(h): One million watt-hours (megawatt-hour).

Nacelle: The back-end of a wind turbine that houses the gearbox, drive train and control electronics.

Net Excess Generation (NEG): The amount of gross generation less the electrical energy consumed at the generating station(s) for station service or auxiliaries.

Net Metering: For electric customers who generate their own electricity, net metering allows for the flow of electricity both to and from the customer – typically through a single, bi-directional meter. When a customer's generation exceeds the customer's use, electricity from the customer flows back to the grid, offsetting electricity consumed by the customer at a different time during the same billing cycle.

Original Equipment Manufacturer (OEM): An OEM manufactures products or components that are purchased by a company and retailed under the purchasing company's brand name.

Perennial Grasses: Unlike corn, which must be replanted every year, perennial grasses, such as switchgrass and Miscanthus, preserve and increase carbon stores in the soil. These and other grasses have been proposed as high-energy alternative feedstocks for biofuel production.

Photovoltaic (PV) Module: An integrated assembly of interconnected photovoltaic cells designed to deliver a selected level of working voltage and current at its output terminals, packaged for protection against environment degradation, and suited for incorporation in photovoltaic power systems. It is also known as a solar module or solar panel.

Polyitaconic Acid: A water soluble polymer with a 2 million metric ton per year market potential as a replacement for petrochemical dispersants, detergents, and super-absorbents.

Power Purchase Agreement (PPA): A legal contract in which a power purchaser purchases the energy produced, and sometimes the capacity and/or additional services, from an electricity generator.

Primary Mill Resource: Mill residues that include wood materials (coarse and fine) and bark generated at manufacturing plants (primary wood-using mills) when round wood products are processed into primary wood products, such as slabs, edgings, trimmings, sawdust, veneer clippings and cores, and pulp screenings.

Production Incentives/Performance-Based Incentives: Performance-based incentives (PBIs), also known as production incentives, provide cash payments based on the number of kilowatt-hours (kWh) or BTUs generated by a renewable energy system. A "feed-in tariff" is an example of a PBI.

Production Tax Credit (PTC): A federal tax credit based on the per kWh of electricity sold by a taxpayer from a qualifying facility to an unrelated entity. For facilities selling electricity generated from wind, closed-loop biomass and geothermal sources, the PTC rate is 1.5 cents per kWh, which is adjusted for inflation and is 2.1 cents per kWh in 2009. For persons selling electricity generated from open-loop biomass, landfill gas, trash, qualified hydropower or marine and hydrokinetic sources, the credit rate is half the credit rate for wind (1.1 cents per kWh in 2009). The PTC can be made for sales in the first 10 years from the time the facility is originally placed in service.

Property-Assessed Renewable Energy (PACE) Financing: A Property Assessed Clean Energy loan program provides residential and commercial property owners with a loan for energy efficiency and renewable energy measures which is subsequently paid back over a certain number of years via an annual charge on their property tax bill.

Public Benefit Funds (PBF): Public benefits funds (PBFs), or clean energy funds, are typically created by levying a small fee or surcharge on electricity rates paid by customers (i.e., system benefits charge [SBC]). The resulting funds can be used to support clean energy supply (i.e., renewable energy, energy efficiency, and combined heat and power [CHP]).

Renewable Energy Credit (REC): A REC, also known as a green tag or renewable energy certificate, represents the property rights to the environmental, social, and other non-power qualities of renewable electricity generation. A REC, and its associated attributes and benefits, can be sold separately (unbundled) from the underlying physical electricity associated with a renewable-based generation source or together (bundled). When unbundled, it is also known as a tradable renewable energy certificate (TREC). A solar renewable energy credit (SREC) is a REC specifically generated by solar energy.

Renewable Energy Resources: Energy resources that are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include: biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action.

Renewable Energy Zones (REZ): Renewable energy zones are special areas designated for renewable energy generation based on land suitability, resource potential, and existing renewable energy generation. Electric transmission infrastructure is constructed in those zones to move renewable energy to markets where people use energy.

Renewable (Green) Diesel: Renewable diesel is produced by hydrotreating or hydrocracking plant oils or animal fats. Unlike biodiesel, it has chemical properties identical to petroleum diesel.

Renewable Portfolio Standard (RPS): A regulatory mechanism requiring that retail electricity suppliers procure a minimum quantity of eligible renewable energy by a specific date, in percentage, megawatt hour, or megawatt terms.

Revolving Loan Fund: A capitalized fund, typically maintained by a state government, that provides low–interest loans for energy efficiency improvements, renewable energy, and distributed generation. As the loans are repaid, they are deposited back into the fund for redistribution as subsequent loans.

Salvage Value: The estimated value that an asset will realize upon its sale at the end of its useful life.

Secondary Mill Resource: Materials leftover after the processing of wood scraps and sawdust from woodworking shops, furniture factories, wood container and pellet mills, and wholesale lumberyards.

Solar and Wind Access Laws: Solar and wind access laws are designed to establish a right to install and operate a solar or wind energy system at a home or other facility. Some solar access laws also ensure a system owner's access to sunlight.

Solar Thermal: A solar energy system that collects or absorbs solar energy for heat or electricity. Solar thermal systems can be used to generate high temperature heat (for electricity production and/or process heat), medium temperature heat (for process and space/water heating and electricity generation), and low temperature heat (for water and space heating and cooling).

Switchgrass: A native warm-season, perennial grass indigenous to the Central and North American tall-grass prairie into Canada. The plant is an immense biomass producer that can reach heights of 10 feet or more. Its high cellulosic content makes switchgrass a candidate for ethanol production as well as a combustion fuel source for power production.

Systems Benefit Charge: See **Public Benefit Fund**.

Metric Ton: A metric unit of measurement equal to 1000 kilograms, used to measure biomass.

Ton: An imperial unit of measurement equal to 2240 pounds.

Waste Heat to Power (WH2P): Capturing industrial waste heat for power generation.

Wood Pellet: Saw dust compressed into uniform diameter pellets to be burned in a heating stove.

*Glossary sources**:** Database of State Incentives for Renewables & Efficiency (DSIRE), Department of Energy Office of Energy Efficiency and Renewable Energy (EERE), Energy Information Administration (EIA), Environmental Protection Agency (EPA), National Renewable Energy Laboratory (NREL), International Energy Agency (IEA).*

APEX IN THE NEWS

APEX
CLEAN ENERGY

Apex Clean Energy Sells 147 MW Grant Plains Wind

Grant County, OK – August 29, 2016 – Southern Power, a subsidiary of Southern Company, and Apex Clean Energy (Apex) today **announced** Southern Power's acquisition of the 147 MW Grant Plains Wind facility from Apex. This is the third facility that Southern Power has purchased from Apex, along with the nearby Grant Wind and Kay Wind.

Apex is managing construction of Grant Plains Wind and will perform asset management services for the facility on behalf of Southern Power upon commercial operation, which is expected in December of this year.

Mark Goodwin, president and COO of Apex, remarked, "Southern Power has been a strong partner for Apex, and we are pleased to be working on our third wind facility with them."

Grant Plains Wind will consist of 64 Siemens turbines in Grant County, Oklahoma.

About Apex

Apex Clean Energy builds, owns, and operates utility-scale wind and solar power facilities. Last year, Apex was the market leader in the United States, with 1,042 megawatts of new wind capacity installations, enough clean energy to supply the population of a city the size of Boston or San Francisco each year for the life of the facilities.

With a team of over 200 professionals and the nation's largest wind energy project pipeline, Apex is a leader in the transition to a clean energy future. For more information, visit **apexcleanenergy.com**.

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Kay Wind Wins in O&M

Kay Wind Recognized for Wind Farm Team of the Year at Wind Operations and Management Conference

Charlottesville, VA – April 13, 2016 – On April 10, the team at Kay Wind, which is operated by Apex Clean Energy and owned by Southern Power, was recognized for its exceptional achievement in operations and management at the Wind O&M conference in Dallas, Texas. The project team won the "Wind Farm Team or Technician of the Year" award for 2017.

In total, the conference's awards saw over 100 entries from across the globe. This particular honor praised the Kay team for placing an emphasis on safety and collaboration and going above and beyond in all their work.

The Kay Wind team has leveraged safe practices and excellent relationships with contractors and local residents to improve operational performance, ensure outstanding service, and earn the confidence of the wind farm's community. The crew has worked with local emergency responders to improve communications and implement wind farm–specific trauma training and education, including an Air Evac transportation simulation.

"Since the project's completion in 2015, the team's commitment to safe operations, the highest standards for performance, and dedication to the local community have changed the perception of wind farms in smaller communities like Kay County," said Andrea Miller, vice president of Asset Management for Apex. "It is of paramount importance to our team to ensure that we deliver on the promises made to our stakeholders and to the communities in which we operate. We are very proud of the acknowledgement of the success of the Kay team, and we are happy that our stakeholders, the community, and our industry know that Apex's employees are invested in the safe operations and long-term success of not only the Kay Wind site, but also the community."

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About Apex Clean Energy

Apex Clean Energy builds, owns, and operates utility-scale wind and solar power facilities. Apex was the U.S. market leader in 2015 and has brought 1,662 MW online over the past two years.

With a team of over 200 professionals and the nation's largest wind energy project pipeline, Apex is a leader in the transition to a clean energy future. For more information, visit www.apexcleanenergy.com.

Apex Clean Energy to Operate IKEA Canada Wind Farm, Wintering Hills

Project is Third IKEA Partnership with Apex

Charlottesville, VA – January 30, 2017 – Apex Clean Energy (Apex) announced today a multi-year contract with IKEA Canada to manage and provide remote operations for the Wintering Hills wind farm located in Alberta, Canada. The 88 MW facility produces enough power to supply approximately 26,000 Canadian homes.

IKEA US purchased two U.S. wind farms from Apex: the 165 MW Cameron Wind facility located in Cameron County, Texas, in November 2014; and the 98 MW Hoopeston Wind facility located in Hoopeston, Illinois, in April 2014. Apex operates and maintains both facilities.

"This expansion of our Asset Management business sends a strong signal to the market," said Mark Goodwin, president and CEO of Apex.

Apex put more wind energy on the U.S. grid than any other company in 2015. Looking ahead, Apex also has the industry's largest and most diverse pipeline of projects in active development. The Wintering Hills facility is the eleventh project in the Apex Asset Management fleet, bringing the total generation under management up to 1,729 MW.

"Wind asset management is a science, and we're able to use the science to safely and reliably push the boundaries of performance," said Andrea Miller, vice president of asset management for Apex. "When it comes to getting maximum power and profit from a wind farm, we measure and analyze the data that others aren't, so we can take action on opportunities and realize gains that others don't."

The Wintering Hills project consists of 55 General Electric 1.6 MW turbines, each with a hub height of 80 meters and a nominal speed of 16.8 rpm.

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About Apex Clean Energy

Apex Clean Energy builds, owns, and operates utility-scale wind and solar power facilities. Apex was the U.S. market leader in 2015 and has brought 1,460 MW online over the past two years.

With a team of over 200 professionals and the nation's largest wind energy project pipeline, Apex is a leader in the transition to a clean energy future. For more information, visit apexcleanenergy.com.

Virginia's Rocky Forge Wind Farm Approved

Rocky Forge Wind Given Green Light by Virginia Department of Environmental Quality

Charlottesville, VA – March 2, 2017 – The Virginia Department of Environmental Quality (DEQ) has approved Apex Clean Energy's "Permit by Rule" (PBR) application for the Rocky Forge Wind project, marking the first time such a project has received the statewide approval and a key milestone for Virginia's clean energy economy.

Rocky Forge Wind is a 75-to-80-megawatt project located in a remote section of northern Botetourt County. The project will provide enough electricity to power up to 20,000 homes annually while providing $20 million to $25 million in state and local tax revenue throughout the project's life and creating jobs during construction and beyond.

"Wind energy will help drive the Virginia economy forward, especially in terms of creating great jobs," said Mark Goodwin, president and CEO of Apex Clean Energy. "In addition to new opportunities related to the construction and operation of Rocky Forge Wind in Botetourt County, Apex employs more than 200 people today in Charlottesville. Linked with competitive pricing and clear evidence that new clean energy generation attracts major corporate investment, Rocky Forge Wind is set to begin a new chapter in Virginia's energy future."

The PBR process itself required more than two years of consultation and study with the DEQ and other agencies in the Secretariat of Natural Resources. The permit application covered each phase of constructing and operating Rocky Forge Wind, from pre-construction natural resource analyses to post-construction monitoring.

Rocky Forge Wind previously received unanimous approval at all levels of local permitting as well as the endorsement of the local chapter of the Sierra Club, the Virginia Deer Hunters Association, and the Virginia Conservation Legacy Fund, among other groups.

"Rocky Forge will be a large contributor to Botetourt County's tax base, while having a minimal effect on existing land use of the thousands of acres of rural land in the project area," said Jack Leffel, chairman of the Botetourt County Board of Supervisors. "This seems like a win-win to me."

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About Apex Clean Energy

Apex Clean Energy builds, owns, and operates utility-scale wind and solar power facilities. Apex was the U.S. market leader in 2015 and has brought 1,460 MW online over the past two years.

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The IKEA Group Makes Largest Wind Farm Investment to Date

165 MW Cameron Wind Farm in Texas is Single Largest IKEA Renewable Energy Investment Globally

[Conshohocken, PA – November 18, 2014] The IKEA Group announced today that it has purchased its second wind farm in the United States from Apex Clean Energy: a 165-megawatt wind farm in Cameron County, Texas. This represents the single largest renewable energy investment made by the IKEA Group globally to date. The wind farm will contribute significantly to the IKEA Group 2020 goal of producing as much renewable energy as the total energy the company consumes globally. The Cameron Wind farm is expected to be fully operational in late 2015.

Earlier this year IKEA Group announced its first U.S. wind farm purchase located in Hoopeston, Illinois. The Cameron Wind farm will be more than one-and-a-half times the size of the Hoopeston project. Together, the IKEA Hoopeston and Cameron wind farms are expected to generate nearly 1,000 gigawatt hours of electricity per year, which is equivalent to the average annual electricity consumption of around 90,000 American households.[1]

“IKEA believes that the climate challenge requires bold commitment and action,” says Rob Olson, IKEA US Acting President and CFO. “We invest in renewable energy to become more sustainable as a business and also because it makes good business sense. And as a home furnishings retailer with sustainability in our roots, we are committed to providing products and solutions that help our customers be more sustainable in their everyday lives.”

IKEA Group has now committed to own and operate 279 wind turbines in nine countries, and will invest a total of $1.9 billion[2] in wind and solar power up to the end of 2015. IKEA has also taken steps to further the development of a low-carbon economy by supporting key initiatives including the People’s Climate March, UN Climate Summit, RE100, and the Climate Declaration.

Mark Kenber, CEO of the non-profit organization The Climate Group, said: “IKEA was one of the first major companies to recognize that tackling climate change makes good business sense. IKEA has set commendable renewable energy targets for its own company, and its actions are positively influencing business practices and the energy market. It has played an instrumental role in setting up ‘RE100’, The Climate Group’s global initiative to support businesses in switching to 100% renewable power.”

IKEA renewable energy investments in the U.S. to date now include: 104 wind turbines located on wind farms in Hoopeston and Cameron; 165,000 solar panels installed on 90% of IKEA buildings across the U.S., providing an additional 38 megawatts installed capacity; and geothermal integrated into the heating and cooling systems of two U.S. store locations, in Centennial, Colorado, and Merriam, Kansas.

Cameron Wind is located in a particularly favorable wind area in the south of Texas, which is the leading state in the U.S. for wind energy production. The wind farm will be fully owned by the IKEA Group and will be constructed and managed by renewable energy company Apex Clean Energy. The project will use 55 Acciona Windpower 3-megawatt turbines.

“Apex is excited to partner with IKEA once again to bring clean, renewable energy from wind to market in the U.S.,” added Apex President, Mark Goodwin. “Both companies understand that this abundant resource is great for the planet, great for our business and great for our shared future.”

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[1] Calculated using the U.S. Energy Information Administration’s ‘Average Residential Monthly Bill by Census Division and State’: http://www.eia.gov/electricity/sales_revenue_price/html/table5_a.html

[2] Calculated at 11/17/14 exchange rate (€1=$1.25). IKEA Group made the €1.5 billion commitment in 2009.

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About IKEA

The IKEA vision is to create a better everyday life for the many people. Our business idea supports this vision by offering a wide range of well-designed, functional home furnishing products at prices so low that as many people as possible will be able to afford them. The IKEA Group currently has 315 stores in 27 countries. There are 40 IKEA stores in the United States. In FY14, the IKEA Group had 716 million visitors to the stores and 1.5 billion visitors to IKEA.com. IKEA incorporates sustainability into day-to-day business and supports initiatives that benefit children and the environment. For more information, visit IKEA-USA.com, facebook.com/IKEAUSA, @IKEAUSANews, @IKEAUSA, http://pinterest.com/IKEAUSA/, www.youtube.com/IKEAUSA, www.theshare-space.com, www.theshare-space.com/en/Blog

About Apex Clean Energy

Apex Clean Energy is an independent renewable energy company based in Charlottesville, VA. Since its founding in 2009, Apex has become

one of the fastest-growing companies in the industry. In 2012, Apex completed the 300 MW Canadian Hills wind energy project. The company currently has 265 MW of new renewable energy facilities under construction and an additional 750 MW contracted and scheduled for completion in 2015. Apex also has a diversified portfolio of wind energy facilities in development around the country and owns several operating solar PV assets. The company's management team comprises experts from throughout the industry whose collective prior experience includes the development, financing, construction and operation of over $10 billion in wind and solar energy facilities now operating in the United States.

Avery Dennison Partners with Apex on Wind Energy PPA; Advances Towards 2025 GHG Reduction Goal

Initiative Follows Avery Dennison Commitments to WWF Climate Savers Program

Glendale, CA and Charlottesville, VA – December 5, 2016 – Global labeling and packaging materials manufacturer Avery Dennison Corporation (NYSE:AVY) has signed a wind power purchase agreement (PPA) with Apex Clean Energy to offset 50 percent of the company's U.S.-based greenhouse gas emissions derived from electricity consumption, signaling commitment by Avery Dennison to renewable energy and energy efficient practices and technology.

Under the agreement with Apex's Perryton Wind, a 299.91 MW wind energy project to be located in Ochiltree County, Texas, Avery Dennison will purchase 20 MW of renewable energy capacity. The PPA is a key component of Avery Dennison's 2025 sustainability goal to reduce absolute greenhouse gas emissions from its operations by at least three percent annually, and by at least 26 percent overall, between 2015 and 2025, made as part of the company's new participation in WWF's Climate Savers Program. Perryton will be Apex's fifth Texas wind farm, powering the equivalent of 108,000 U.S. homes. The facility will consist of 130 Siemens 2.307 MW turbines.

According to Roland Simon, vice president of global procurement and global sustainability leader at Avery Dennison, the partnership with Apex is one of the ways Avery Dennison continues to create shared value for the company, the industry and communities worldwide. He noted that the PPA will provide clean, renewable electricity equal to 50% of the power consumed by Avery Dennison's U.S. operations.

"It's important for us to optimize renewable energy sources in a way that ripples outward to create change that encompasses far more than our own business," said Simon.

Apex, an independent energy solutions provider, was awarded a 2016 Green Power Leadership Award by the Center for Resource Solutions in October for its leadership in bringing wind capacity to market and its expansion of direct purchasing of clean energy by the public and private sectors.

"We leverage the depth and breadth of our national pipeline of projects and we are committed to tailoring solutions that meet the specific goals of our corporate, utility and public sector partners, from a facility purchase to a structured PPA," explained Steve Vavrik, Apex's chief commercial officer. "The commitment to long-term renewable energy purchasing by companies such as Avery Dennison is providing a strong drive in the market to bring more clean energy to the grid," Vavrik added.

Avery Dennison's investment in renewable wind power demonstrates its continued focus on energy efficiency and energy reduction. The agreement with Apex comes on the heels of Avery Dennison joining WWF's Climate Savers Program, a global group of partner companies engaged in the transition to a climate-friendly economy.

(cont.)

Additional goals set with WWF include covering the equivalent of 100 percent of electricity consumption at Avery Dennison's U.S. operations with renewable energy by 2025 and addressing climate change through other areas of operations, such as maximizing use of paper made with recycled or certified wood fiber (sourcing only from certified sources by 2025).

"We recognize Avery Dennison for its strong leadership in sourcing more renewable energy to help achieve the company's emission reduction target," said Matt Banks, climate and business manager at WWF. As our newest Climate Savers partner and as a signatory of the Renewable Energy Buyers Principles, Avery Dennison has called for increased access to cost-effective renewable energy that will lead to measurable reductions in its greenhouse gas emissions while demonstrating to other companies the business and environmental value of scaling up to achieve a 2025 target."

"Working in partnership with WWF is part of our commitment to sustain a thriving business that is a force for good—one that generates value, in every respect, for all involved," said Simon.

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About Avery Dennison

Avery Dennison (NYSE:AVY) is a global leader in labeling and packaging materials and solutions. The company's applications and technologies are an integral part of products used in every major market and industry. With operations in more than 50 countries and more than 25,000 employees worldwide, Avery Dennison serves customers with insights and innovations that help make brands more inspiring and the world more intelligent. Headquartered in Glendale, California, the company reported sales of $6 billion in 2015. Learn more at www.averydennison.com.

About Apex Clean Energy

Apex Clean Energy builds, owns, and operates utility-scale wind and solar power facilities. Apex was the U.S. market leader in 2015 and has brought 1,460 MW online over the past two years. Apex recently coauthored, with the American Council on Renewable Energy (ACORE), the new "Renewable Energy PPA Guidebook for Corporate and Industrial Purchasers," which is intended to serve as a guide to the often complex PPA contracting process and is designed for companies unfamiliar with the key elements of successful PPAs. With a team of over 200 professionals and the nation's largest wind energy project pipeline, Apex is a leader in the transition to a clean energy future. For more information, visit www.apexcleanenergy.com.

STEELCASE ANNOUNCES NEW WIND POWER INVESTMENT WITH APEX CLEAN ENERGY

25 Megawatt Power Purchase Agreement Further Diversifies the Furniture Company's Renewable Energy Portfolio

Grand Rapids, Mich. – February 2, 2016 – **Steelcase Inc.** (NYSE: SCS), the global leader in the office furniture industry, announced a 12-year power purchase agreement (PPA) with Apex Clean Energy for 25 megawatts of wind power. Since 2014, Steelcase has invested in renewable energy credits equivalent to 100% of its global electricity consumption. This latest investment will make up nearly half of Steelcase's renewable energy purchases, directly support the construction of a new clean energy facility set to begin operations in 2016, and further diversify the company's renewable energy portfolio.

"Our decision to partner with Apex and execute a long-term renewable energy agreement reflects our longstanding commitment to drive a clean energy landscape," said Jim Keane, Steelcase president and CEO. "At a time when businesses and governments are working to align on climate strategies, we maintain a sense of urgency and optimism. We are focused on finding new ways to reduce our overall energy use and investing in innovative, economically beneficial projects like this one to take one step closer to a sustainable energy future."

Under Steelcase's long-term PPA with Apex's Grant Plains Wind project, a 150-megawatt facility in Grant County, Oklahoma, Steelcase is committed to support production of approximately 100 million kilowatt-hours of clean, renewable wind energy each year. This amount is equal to approximately 70% of Steelcase's U.S. electricity usage, or roughly the electricity needed to power 9,100 homes per year.

"Apex is proud to partner with Steelcase to help the company achieve its renewable energy goals," said Mark Goodwin, president of Apex. "Our mission is to accelerate the shift to clean energy, and we do so by providing opportunities for visionary companies like Steelcase to participate in the energy market in the manner that makes the most

sense for them. Steelcase has proven itself to be a leader in renewables investment, and we're pleased that Grant Plains Wind fits with its corporate strategy."

"After a record-setting 2015 for corporate renewable energy purchasing, we commend Steelcase for starting off 2016 with such a powerful long-term commitment for clean wind energy," said Lily Donge, a principal at nonprofit Rocky Mountain Institute and its Business Renewables Center, of which Steelcase and Apex are a member and sponsor, respectively.

Steelcase has a long history of supporting renewable energy development that dates back to 2001. The company is one of the top 50 green power users in the United States, according to the Environmental Protection Agency (EPA), and received a Green Power Leadership Award from the EPA in 2014.

About Steelcase
For over 100 years, Steelcase Inc. has helped create great experiences for the world's leading organizations, across industries. We demonstrate this through our family of brands, including Steelcase®, Coalesse®, Designtex®, PolyVision® and Turnstone®. Together, they offer a comprehensive portfolio of architecture, furniture and technology products and services designed to unlock human promise and support social, economic and environmental sustainability. We are globally accessible through a network of channels, including over 800 dealer locations. Steelcase is a global, industry-leading and publicly traded company with fiscal 2015 revenue of $3.1 billion.

About Apex
Apex Clean Energy builds, owns, and operates utility-scale wind and solar power facilities. Last year, Apex completed 1,042 megawatts of new wind capacity, enough to power over half a million homes. With the nation's largest wind energy project pipeline and billions of dollars worth of operating assets under management, Apex is a leader in the transition to a clean energy future. For more information, visit **www.apexcleanenergy.com**.

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U.S. ARMY SIGNS POWER PURCHASE AGREEMENT WITH APEX CLEAN ENERGY FOR HYBRID WIND/SOLAR ENERGY PROJECT

Charlottesville, VA – January 20, 2016 – Defense Logistics Agency (DLA) Energy, in coordination with the U.S. Army Office of Energy Initiatives (OEI) and Fort Hood, has signed a Renewable Energy Supply Agreement (RESA) with Apex Clean Energy Holdings, LLC, for 65.8 MW of electricity from a combination of large-scale renewable energy solar and wind facilities to serve Fort Hood in Texas. The Army is expected to pay about $168 million less than what it would pay for power from the traditional electricity grid over the course of the 28-year agreement.

Apex's groundbreaking hybrid energy project—the Army's largest single renewable energy project to date—is sized to optimize the solar energy produced by the Phantom Solar facility on-site at Fort Hood and the wind energy produced at the Cotton Plains Wind energy facility in Floyd County, Texas. Apex is collaborating with two Service-Disabled Veteran-Owned Small Businesses in the development and construction of the project, Tennessee Valley Infrastructure Group (TVIG) and American Helios. TVIG will serve as the Balance of Plant contractor on the wind energy component project, and American Helios Constructors will support construction of the solar component of the project.

"The project at Fort Hood, the Army's first hybrid and largest single renewable energy project to date, is an excellent example of the extraordinary results we can achieve through collaboration," said Katherine Hammack, assistant secretary of the Army for installations, energy, and environment. "The Army will continue to partner with private-sector entities such as Apex Clean Energy, Inc., to expand renewable energy initiatives on our installations. By working together, we can ensure a sustainable world for future generations."

“We are proud to be working with several Service-Disabled Veteran-Owned Small Businesses to support the Department of Defense’s goals to preserve energy surety and harness more clean, domestic energy to power military facilities,” said Mark Goodwin, Apex Clean Energy president. “As a veteran myself, I am honored to be partnering with the Army on a renewable energy project that will ensure a consistent, affordable, and secure energy resource for Fort Hood for years to come.”

Apex’s hybrid project will feature 50.4 MW of wind energy from the Cotton Plains Wind energy facility in Floyd County, Texas, and 15.4 MWac solar on-site at Fort Hood. The project will begin providing energy to Fort Hood in 2017.

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Western Farmers Electric Cooperative Signs 50 MW Renewable Energy Purchase Agreement with Apex Clean Energy, Saves Money for Oklahoma Consumers

CORRECTED JANUARY 26, 2015: Tax revenue estimate amended from $28 million to $14 million to reflect updated calculations.

Anadarko, Oklahoma – January 19, 2015 – Apex Clean Energy, through its subsidiary Grant Wind, LLC, has signed a Renewable Energy Purchase Agreement (REPA) with Western Farmers Electric Cooperative (WFEC) for 50 megawatts (MW) of wind energy from Apex's Grant Wind project. With this agreement, Apex has sold the remaining 50 MW of the 150 MW capacity project, which will produce enough electricity to power more than 56,000 U.S. homes. The project is expected to come online in 2015.

This REPA is the second such transaction between WFEC and Apex Clean Energy. The first 100 MW REPA was announced in November 2013.

Mark Goodwin, Apex Clean Energy president said, "The Grant Wind project will harness Oklahoma's clean, abundant wind resources to produce pollution-free power that will lower electric bills for Oklahoma consumers."

"Unlike other energy sources, a tremendous advantage of wind is it utilizes no water. This is critical to helping Oklahoma conserve its water resources after several years of extreme drought," said Goodwin. "We could not be more pleased to be working with Western Farmers Electric Cooperative once again to bring jobs and new revenue to Grant County. Apex is making these economic and energy infrastructure investments in Oklahoma because of its robust wind resource and supportive state policies. Oklahoma has become a leader in wind energy nationally and this project furthers that status."

Over its lifetime, the Grant Wind project is projected to provide more than $14 million in tax revenue to fund community schools, roads and other local needs. Approximately $1 million will be paid annually to Oklahoma landowners who hold leases for the Grant Wind project. Additionally, it is estimated the project will bring more than $182 million in economic activity to the Grant County area with approximately 61 jobs for the construction and operation of the wind farm.

"WFEC is pleased to once again be working with Apex Clean Energy. We are also excited to add this additional economical and environmentally friendly wind energy resource into our generation mix," explained Brian Hobbs, vice president, legal and corporate services at WFEC.

“With this additional 50 MW, WFEC continues to take advantage of opportunities to add wind energy resources to our generation portfolio in a manner that helps manage long-term cost of service to our rural member consumers in an environmentally responsible manner,” Hobbs pointed out. “Wind energy helps provide valuable diversity to our generation portfolio.”

About Apex

Apex Clean Energy is an independent renewable energy company focused on building utility-scale generation facilities. Apex is building one of the nation’s largest, most-diversified portfolios of renewable energy resources, capable of producing more than 10,000 MW of clean energy. Apex has announced more than 750 MW of power purchase agreements since 2013. In the coming year, Apex will bring five new U.S. wind energy facilities online, comprising of more than 1,000 MW of capacity. Apex will provide asset management services on three of these facilities, representing more than 500 MW of capacity. For more information, visit www.apexcleanenergy.com.

About WFEC

WFEC is a generation and transmission (G&T) cooperative that provides essential electric service to 22 member cooperatives, Altus Air Force Base, and other power users. These members are located primarily in Oklahoma and New Mexico, with some service territories extending into portions of Texas and Kansas. Now in its 74th year of operation, WFEC has a diverse mix of power supply resources including owned generation facilities, as well contract power purchases, including wind, fossil fuel and hydropower resources. WFEC owns and maintains more than 3,700 miles of transmission line to some 264 substations and 59 switch stations. For more information, visit www.wfec.com.

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News

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Sept. 9, 2015

Southern Company subsidiary to acquire second wind project, surpassing 1,600 MW of renewable generation development

ATLANTA – Southern Company subsidiary Southern Power today announced an agreement to acquire the company's second wind project – the 151-megawatt (MW) Grant Wind facility in Oklahoma – from Apex Clean Energy. The acquisition is expected to close in March 2016 upon successful completion of project construction.

"Southern Company is committed to the full portfolio and this project is an important step in further expanding our fuel mix," said Southern Company Chairman, President and CEO Thomas A. Fanning. "Our second wind project and one of Southern Power's more than 20 renewable projects across America, the Grant Wind facility is a smart investment that expands our company's presence in a region with exceptional wind resources."

In March, Southern Power announced an agreement to acquire its first wind project – the 299-MW Kay Wind facility in Oklahoma, also from Apex Clean Energy – which is expected to close in the fourth quarter of 2015.

With the addition of the Grant Wind facility, Southern Power's renewable ownership is expected to reach more than 1,600 MW, with 21 solar, wind and biomass facilities either announced, acquired or under construction. Across its system, Southern Company has added or announced more than 3,400 MW of renewable generation since 2012.

Located in Grant County, Oklahoma, the project is expected to utilize 66 wind turbines manufactured by Siemens and will be capable of generating enough electricity to help meet the energy needs of approximately 50,000 average U.S. homes.

Apex Clean Energy is managing the construction of Grant Wind and, upon completion, will operate and maintain the facility. IEA Renewable Energy, a wholly owned subsidiary of Infrastructure and Energy Alternatives (IEA), is serving as the engineering, procurement and construction contractor. Construction began in August, and the plant is expected to achieve commercial operation in March 2016.

The electricity and associated renewable energy credits (RECs) generated by the facility will be sold under 20-year power purchase agreements with Western Farmers Electric Cooperative, East Texas Electric Cooperative and Northeast Texas Electric Cooperative. The companies have each contracted for approximately 50 MW and will have the option to either keep or sell the RECs.

The Grant Wind project fits Southern Power's business strategy of growing its wholesale business through the acquisition and construction of generating assets substantially covered by long-term contracts.

Southern Power, a subsidiary of Southern Company, is a leading U.S. wholesale energy provider meeting the electricity needs of municipalities, electric cooperatives and investor-owned utilities. With the completion of this acquisition, Southern Power and its subsidiaries will own or have rights to 30 facilities operating or under construction in nine states with more than 10,200 MW of generating capacity in Alabama, California, Florida, Georgia, Nevada, New Mexico, North Carolina, Oklahoma and Texas.

With more than 4.5 million customers and approximately 46,000 megawatts of generating capacity, Atlanta-based Southern Company (NYSE: SO) is the premier energy company serving the Southeast through its subsidiaries. A leading U.S. producer of clean, safe, reliable and affordable electricity, Southern Company owns electric utilities in four states and a growing competitive generation company, as well as fiber optics and wireless communications. Southern Company brands are known for excellent customer service, high reliability and affordable prices that are below the national average. Through an industry-leading commitment to innovation, Southern Company and its subsidiaries are inventing America's energy future by developing the full portfolio of energy resources, including nuclear, 21st century coal, natural gas, renewables and energy efficiency, and creating new products and services for the benefit of customers. Southern Company has been named by the U.S. Department of Defense and G.I. Jobs magazine as a top military employer, listed by Black Enterprise magazine as one of the 40 Best Companies for Diversity and designated a 2014 Top Employer for Hispanics by Hispanic Network. The company earned the 2014 National Award of Nuclear Science and History from the National Atomic Museum Foundation for its leadership and commitment to nuclear development, and is continually ranked among the top utilities in Fortune's annual *World's Most Admired Electric and Gas Utility* rankings. Visit our website at www.southerncompany.com.

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Cautionary Note Regarding Forward-Looking Statements:

Certain information contained in this release is forward-looking information based on current expectations and plans that involve risks and uncertainties. Forward-looking information includes, among other things, statements concerning the consummation of the acquisitions of the Grant Wind facility in Oklahoma and the Kay Wind facility in Oklahoma, the construction and subsequent operation of the Grant Wind facility and the future generating capacity of Southern Power and its subsidiaries' facilities. Southern Company and Southern Power caution that there are certain factors that can cause actual results to differ materially from the forward-looking information that has been provided. The reader is cautioned not to put undue reliance on this forward-looking information, which is not a guarantee of future performance and is subject to a number of uncertainties and other factors, many of which are outside the control of Southern Company and Southern Power; accordingly, there can be no assurance that such suggested results will be realized. The following factors, in addition to those discussed in each of Southern Company's and Southern Power's Annual Reports on Form 10-K for the year ended December 31, 2014, and subsequent securities filings, could cause actual results to differ materially from management expectations as suggested by such forward-looking information: the ability to control costs and avoid cost overruns during the development and construction of generating facilities, to construct facilities in accordance with the requirements of permits and licenses, and to satisfy any operational and environmental performance standards, including the requirements of tax credits and other incentives; and potential business strategies, including acquisitions or dispositions of assets or businesses, which cannot be assured to be completed or beneficial to Southern Company or Southern Power. Southern Company and Southern Power expressly disclaim any obligation to update any forward-looking information.

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Apex Clean Energy Secures $216 Million Construction Loan for the Grant Wind Project

Charlottesville, VA – September 9, 2015 – Apex Clean Energy, an independent renewable energy company, is pleased to announce it has reached financial close of a $216 million construction loan for the 151 MW Grant Wind project in Grant County, Oklahoma.

Bayerische Landesbank, New York Branch, acted as the Joint Lead Arranger, Coordinating Mandated Lead Arranger, and Bookrunner for the transaction. Additionally, KeyBank National Association and Siemens Financial Services, Inc., acted as Joint Lead Arrangers. Bayerische Landesbank is the Administrative Agent, Collateral Agent, and LC Issuing Bank. The project is expected to utilize 66 wind turbines manufactured by Siemens and will be capable of generating enough electricity to help meet the energy needs of approximately 50,000 average U.S. homes.

“We are very pleased to be working with these industry leaders to bring another premiere wind generation asset to market,” said Mark Goodwin, president of Apex Clean Energy.

“BayernLB is dedicated to offering our clients the solutions they need to expand their business, and we are thrilled to have supported Apex again on this financing,” said Alexander von Dobschütz, Global Head of Structured & Trade Finance at BayernLB.

Western Farmers Electric Cooperative, East Texas Electric Cooperative, and Northeast Texas Electric Cooperative have signed agreements to purchase the power and associated renewable energy credits (RECs) produced by Grant Wind. Each will have the option to keep or sell the RECs it receives. Southern Company subsidiary Southern Power has announced an agreement to acquire Grant Wind upon successful completion of project construction. Apex will provide comprehensive asset management services led by an on-site operations team and supported by Apex’s Remote Operations Control Center located in Charlottesville, Virginia.

Apex believes that Grant Wind is expected to generate about $500,000 per year on average in tax revenues for local counties and school districts, $1 million per year on average in royalty payments to local landowners, 100 local jobs during construction, and about 8 high-quality long-term jobs throughout operation.

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About Apex

Apex Clean Energy is an independent renewable energy company focused on building utility-scale generation facilities. Apex is constructing one of the nation’s largest, most diversified portfolios of renewable energy resources, capable of producing more than 12,000 MW of clean energy. This year, Apex is bringing five new U.S. wind energy facilities online, comprising 1,161 MW of capacity. Apex will provide asset management services on four of these facilities. For more information, visit www.apexcleanenergy.com.

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IKEA Makes First Wind Farm Investment in the United States

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98 MW Hoopeston Wind Project Is the Largest Single IKEA Renewable Energy Investment Globally to Date

(Conshohocken, PA – April 10, 2014) IKEA US announced today that it is making its first wind farm investment in the United States with the purchase of Hoopeston Wind in Hoopeston, Illinois. The 98 megawatt wind farm is the largest single IKEA Group renewable energy investment globally to date and will make a significant contribution to the company's goal to generate as much renewable energy as the total energy it consumes by 2020. The project is currently being constructed by Apex Clean Energy and is expected to be fully operational by the first half of 2015.

"The US has amazing wind and sun resources that will never run out. We are delighted to make this investment -- it is great for jobs, great for energy security, and great for our business. Importantly, it's great for the future of our climate," says Steve Howard, Chief Sustainability Officer, IKEA Group.

The announcement was made by Rob Olson, Chief Financial Officer of IKEA US, at a business executive briefing by Climate Declaration signatories for members of the Bi-Cameral Task Force on Climate Change focusing on climate-related business impacts, strategies companies are using to lower their carbon footprints, and the policies needed to mitigate climate change and boost clean energy sources.

"We are committed to renewable energy and to running our business in a way that minimizes our carbon emissions, not only because of the environmental impact, but also because it makes good financial sense," said Olson. "We invest in our own renewable energy sources so that we can control our exposure to fluctuating electricity costs and continue providing great value to our customers."

The wind farm purchase is also indicative of the IKEA commitment to growth in the United States. IKEA will open three new stores in 2014 and 2015, and last month announced plans to expand its manufacturing partnership with a key US supplier.

Hoopeston Wind is expected to generate up to 380 GWh of renewable energy each year, which is equivalent to any of the following, calculated annually:

- The electricity needs of 34,000 average American households[1]
- A reduction in CO2 emissions equal to taking 55,000 cars off the road [2]

[1] Calculated using estimated project Net Capacity Factor and the U.S. Energy Information Administration's 'Average Residential Monthly Bill by Census Division and State'.
(http://www.eia.gov/electricity/sales_revenue_price/html/table5_a.html)

[2] http://www.epa.gov/cleanenergy/energy-resources/calculator

- 165% of the electricity consumed by IKEA US (38 stores, five distribution centers, two service centers and one factory)
- 130% of the total energy (electricity + heat) consumed by IKEA US
- 18% of the electricity used by IKEA Group worldwide
- 10% of the total energy used by IKEA Group worldwide
- The energy consumed by 70 IKEA stores

The Hoopeston Wind project will install 49 Vestas V100-2.0 MW wind turbines near Hoopeston in Vermilion County, Illinois, approximately 110 miles south of Chicago.

Hoopeston Wind will be fully owned by the IKEA Group and managed by US-based wind and solar developer Apex Clean Energy. Apex President Mark Goodwin said, "Wind energy has been the fastest growing source of new energy generation in the US, and the potential is only beginning to be tapped. This project with IKEA US is an opportunity for Apex to work with a new type of investor and partner to expand wind energy development in this country."

Hoopeston Wind is the most recent in a series of renewable energy investments by the IKEA Group, which has now committed to own 206 wind turbines worldwide. This includes investments in wind farms in eight other countries to date: Canada, where it is now the largest retail wind energy investor; Denmark; France; Germany; Ireland; Poland; Sweden; and the United Kingdom.

IKEA Group has also installed 550,000 solar panels on IKEA buildings in nine countries. In the US, these investments include solar installations completed on 90% of IKEA locations across 20 states, with a total of 165,000 solar panels providing 38 MW installed capacity. In addition, IKEA integrated a geothermal component into the heating and cooling system of the IKEA store in Centennial, CO, with another geothermal project underway as part of a new Kansas City-area store slated to open in Fall 2014.

In 2013, the IKEA Group produced 1,425 GWh of energy from renewable sources, including wind and solar, equivalent to 37% of the company's total energy needs. As part of its People & Planet Positive sustainability strategy, the company has allocated $2 billion to invest in wind and solar until 2015 to get closer to its goal of producing 100% as much renewable energy as the total energy it consumes by 2020. The IKEA Group is also leading in making its operations more energy efficient, and since 2010 has saved nearly $55 million[3] through energy efficiency efforts in IKEA stores and warehouses.

About IKEA

The IKEA vision is to create a better everyday life for the many people. Our business idea supports this vision by offering a wide range of well-designed, functional home furnishing products at prices so low that as many people as possible will be able to afford them. There are currently 305 IKEA Group stores in 26 countries. There are 38 IKEA stores in the US. In FY 13, the IKEA Group had 135,000 co-workers, 684

[3] Euro to dollar conversion based on exchange rate 4/7/14

million visitors to the stores and 1.3 billion visitors to IKEA.com. IKEA incorporates sustainability into day-to-day business and supports initiatives that benefit children and the environment.

For more information, visit IKEA-USA.com, facebook.com/IKEAUSA, @IKEAUSANews, @DesignByIKEA, http://pinterest.com/IKEAUSA/, www.youtube.com/IKEAUSA, www.theshare-space.com, www.theshare-space.com/en/Blog

About Apex Clean Energy

Apex Clean Energy is an independent renewable energy company based in Charlottesville, VA. Since its founding in 2009, Apex has become one of the fastest-growing companies in the industry. In December 2012, Apex completed the development and construction of the 300 MW Canadian Hills Wind project outside Oklahoma City. The company has a diversified portfolio of wind energy facilities in development around the country and owns several operating solar PV assets. The company's management team comprises experts from throughout the industry whose collective prior experience includes the development, financing, construction and operation of over $10 billion in wind and solar energy facilities now operating in the United States.

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Apex Clean Energy Secures $397 Million Construction Loan for the Kay Wind Project

Charlottesville, VA –March 31, 2015 – Apex Clean Energy, an independent renewable energy company, is pleased to announce it has reached financial close of a $397 million construction loan for the 299 MW Kay Wind Project in Kay County, Oklahoma.

Bayerische Landesbank, New York Branch and Rabobank, New York Branch acted as the Joint Lead Arrangers, Coordinating Lead Arrangers and Joint Bookrunners for the transaction. Additionally, Canadian Imperial Bank of Commerce, New York Branch, Commerzbank AG, New York Branch, KeyBank National Association, and Siemens Financial Services, Inc. acted as Joint Lead Arrangers. Rabobank is the Administrative Agent, Collateral Agent and LC Issuing Bank.

"We appreciate the dedication, creativity and financial strength that BayernLB, Rabobank, and the rest of the bank groups have brought to these transactions," said Mark Goodwin, President of Apex Clean Energy. "The participation of these global institutions is a key to the success of the project, which will save local power consumers millions over its lifetime and use no water, conserving about 7.92 million gallons of water per day when compared to what a conventional power plant would use to generate the same amount of energy." Westar and Grand River Dam Authority (GRDA), the purchasers of the power from the project, will have the ability to resell the renewable energy purchased to third parties.

The company believes that Kay Wind is expected to generate about $2.3 million per year in tax revenues for local counties and school districts, $2 million per year in royalty payments to local landowners, 150 local jobs during construction, and more than a dozen high-quality long term jobs throughout operations.

Apex Clean Energy secured long-term power purchase agreements with Westar Energy and GRDA for Kay Wind, which will utilize 130 Siemens 2.3-MW turbines. Westar Energy is based in Topeka, Kansas and GRDA is based in Vinita, Oklahoma. Upon completion, Southern Company subsidiary Southern Power expects to acquire the project from Apex. Apex will provide comprehensive asset management services led by an on-site operations team and supported by Apex's remote operations control center located in Charlottesville, Virginia.

"Rabobank is pleased to be supporting Apex in this important transaction with Southern, especially as it represents a step forward in their strategy to not only develop, but also finance and own, large wind energy projects," said Tom Emmons, Head of US Project Finance of Rabobank.

"We are pleased to support Apex and Siemens, important BayernLB partners, by financing the construction of the Kay Wind project, which will provide competitively priced power to Oklahoma and the region," said Alexander von Dobschütz, Global Head of Structured & Trade Finance at BayernLB.

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About Apex

Apex Clean Energy is an independent renewable energy company focused on building utility-scale generation facilities. Apex is constructing one of the nation's largest, most-diversified portfolios of renewable energy resources, capable of producing more than 10,000 MW of clean energy. Apex has announced more than 750 MW of power purchase agreements since 2013. In the coming year, Apex will bring five new U.S. wind energy facilities online, comprising 1,164 MW of capacity. Apex will provide asset management services on four of these facilities, representing more than 800 MW of capacity. For more information, visit www.apexcleanenergy.com.

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First Reserve Acquires Kingfisher Wind from Apex Clean Energy

Canadian County, OK – January 22, 2015 – First Reserve, the largest global private equity and infrastructure investment firm exclusively focused on energy, today announced an agreement to acquire the Kingfisher Wind power project from Apex Clean Energy ("Apex"), an independent renewable energy company. Kingfisher Wind is a construction-ready 298 MW wind power generation project located in Canadian and Kingfisher Counties.

Kingfisher Wind is expected to bring an estimated $1.5 million per year in new tax revenues to Canadian and Kingfisher Counties. Over the project's lifetime, this is expected to add up to about $30.8 million to local school districts, including $843,000 per year to Okarche School District and $326,000 per year to Cashion School District. In addition, the project is anticipated to inject about $2 million per year into the local economy through annual payments to local landowners.

Apex is active nationwide, with projects currently in construction in Illinois, Oklahoma, and Texas. In 2012, Apex completed the development and construction management of the 300 MW Canadian Hills Wind facility. Apex also recently announced the sale of the 300 MW Balko Wind project in Beaver County, Oklahoma, as well as power purchase agreements for three Oklahoma projects to serve in-state customers Public Service Company of Oklahoma, Western Farmers Electric Cooperative, and Grand River Dam Authority.

"The completion of Kingfisher Wind should bring new opportunities for our school to further improve our class offerings and quality of education," said Okarche School Superintendent Rob Friesen. "When the project goes on line, it should bring approximately $800,000 per year to our district. After visiting with other schools who have benefited from this situation, I can see potential to further enhance the educational opportunities for our students."

Mark Goodwin, Apex Clean Energy President, added, "This transaction highlights Apex's broad capabilities to deliver turn-key clean energy solutions for our financial partners. Apex will continue its involvement in managing all aspects of Kingfisher Wind, from development and construction through long-term asset management."

About Apex

Apex Clean Energy is an independent renewable energy company focused on building utility-scale generation facilities. Apex is building one of the nation's largest, most-diversified portfolios of renewable energy resources, capable of producing over 10,000

MW of clean energy. Apex has announced over 750 MW of power purchase agreements since 2013. In the coming year, Apex will bring five new U.S. wind energy facilities online, comprising over 1,000 MW of capacity. Apex will provide asset management services on three of these facilities, representing over 500 MW of capacity. For more information, please visit www.apexcleanenergy.com.

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Apex Clean Energy Secures $50 Million in Financing from Prudential Capital Group

Charlottesville, VA – February 10, 2015 – Apex Clean Energy, an independent renewable energy company, announced today that it has secured $50 million in financing from Prudential Capital Group. The proceeds of the financing will be utilized to advance Apex's project pipeline, including project development, acquisitions and general corporate purposes.

"We look forward to partnering with Apex. In addition to its strong management team and considerable pipeline, Apex has a compelling project development track record and the resources to expand its platform toward long-term ownership and operation," said Ric Abel, managing director with Prudential Capital Group.

Mark Goodwin, Apex Clean Energy President, added, "We are very pleased to be entering into this long-term relationship with Prudential Capital Group. As we continue to build out our renewable energy pipeline, this capital will support the investments required to push projects forward across our portfolio."

"We founded Apex in 2009, at a time when financial markets were in turmoil, with private investors who shared our commitment to clean energy. Since then, our investment thesis has not changed: the low cost of clean energy has been the key factor driving growth in the market. This is what has enabled our portfolio to deliver compelling returns and attract top-tier investors like Prudential Capital Group. We also see the intrinsic value of clean energy: our reserves are not subject to depletion, our fuel is delivered to our facilities at no cost, and our power plants do not produce emissions or consume water. The cultivation of energy sources with these attributes will enable a more sustainable energy future and deliver long-term value to our shareholders."

About Apex

Apex Clean Energy is an independent renewable energy company focused on building utility-scale generation facilities. Apex is building one of the nation's largest, most-diversified portfolios of renewable energy resources, capable of producing over 10,000 MW of clean energy. Apex has announced over 750 MW of power purchase agreements since 2013. In the coming year, Apex will bring five new U.S. wind energy facilities online, comprising over 1,000 MW of capacity. Apex will provide asset management services on four of these facilities, representing over 800 MW of capacity. For more information, please visit www.apexcleanenergy.com.

About Prudential
Prudential Capital Group has been a leading provider of private debt, mezzanine and equity securities to companies worldwide for more than 70 years. Managing a portfolio of $71.6 billion as of December 31, 2014, Prudential Capital offers senior debt and mezzanine capital, leveraged leases, and equipment finance to companies, worldwide. The global regional office network has locations in Atlanta, Chicago, Dallas, Frankfurt, London, Los Angeles, Milan, Minneapolis, Newark, N.J.; and New York, Paris and San Francisco. For more information, please visit www.prudentialcapitalgroup.com.

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Apex Clean Energy Secures $30 Million in a Second Round of Financing from Prudential Capital Group

Charlottesville, VA – August 13, 2015 – Apex Clean Energy, an independent renewable energy company, announced today that it has secured $30 million in follow-on financing from Prudential Capital Group. This latest investment follows the $50 million in financing that Apex announced with Prudential in February of this year. The proceeds of this financing will be utilized to advance Apex's project pipeline, including project construction, development, acquisitions, and general corporate purposes. The investment will also be used to expand Apex's growing asset management business, which is supported by the company's recently completed remote operations center in Charlottesville, Virginia.

"We're pleased to close our second 2015 transaction with Apex," said Ric Abel, managing director at Prudential Capital Group. "This add-on financing will allow Apex to continue to invest more into its considerable pipeline, and retain many projects deeper into the development cycle before selling to more conventional long-term owners or maintain a long-term stake."

Mark Goodwin, Apex Clean Energy president, added, "We are seeing tremendous interest from the utility, financing, and corporate sectors. This follow-on investment accelerates our projects to serve this growing market."

About Apex

Apex Clean Energy is an independent renewable energy company focused on building utility-scale generation facilities. Apex is constructing one of the nation's most diversified portfolios of renewable energy resources, capable of producing more than 12,000 MW of clean energy. Apex's wind development pipeline is currently the largest in the United States. In the coming year, Apex will bring five new U.S. wind energy facilities online, comprising 1,161 MW of capacity. Apex will provide asset management services on four of these facilities. For more information, visit www.apexcleanenergy.com.

About Prudential

Prudential Capital Group has been a leading provider of private debt, mezzanine and equity securities to companies worldwide for more than 75 years. Managing a portfolio of $74 billion as of March 31, 2015, Prudential Capital offers senior debt and mezzanine capital, leveraged

leases, credit tenant leases, and equipment finance to companies, worldwide. The global regional office network has locations in Atlanta, Chicago, Dallas, Frankfurt, London, Los Angeles, Milan, Minneapolis, Newark, N.J., New York, Paris and San Francisco. For more information, please visit www.prudentialcapitalgroup.com.

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